Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection
One Winter Street Boston, MA 02108 • 617-292-5500

Charles D. Baker
Governor

Karyn E. Polito
Lieutenant Governor

Matthew A. Beaton
Secretary

Martin Suuberg
Commissioner

Draft Massachusetts Exceptional Events Demonstration
May 2016 Fort McMurray Wildfire

April 19, 2017

Contents

1. Overview

The Massachusetts Department of Environmental Protection (MassDEP) is responsible for monitoring outdoor air quality in Massachusetts and developing plans and regulatory programs to reduce emissions of pollutants that adversely affect public health, welfare, and the environment. MassDEP operates an extensive network of air monitoring stations throughout the Commonwealth. During the 2016 ozone season (April 1 – September 30), MassDEP monitored ozone at 15 monitoring stations. The Wampanoag Tribe of Gay Head (Aquinnah) operated an ozone monitoring station in Aquinnah on Martha's Vineyard.

In May 2016, smoke from a very large and long-lasting wildfire in the Fort McMurray area of Alberta, Canada affected air quality from the north-central to the northeast United States, including Massachusetts. During this event maximum daily 8-hour average ozone concentrations exceeded the National Ambient Air Quality Standards (NAAQS) for ozone at several monitors in the Northeast region and in Massachusetts, including at the Chicopee and Ware monitors.

The U.S. Environmental Protection Agency's (EPA) Exceptional Events Rule[1] allows agencies to exclude monitoring data influenced by exceptional events when determining whether an exceedance or violation of the NAAQS has occurred, provided the agency can demonstrate a clear causal relationship between the specific event and monitored concentrations.

MassDEP has prepared this draft demonstration to show that the elevated ozone concentrations recorded at the Chicopee and Ware monitoring stations on two of the affected days (May 25 and 26) were the result of high levels of ozone and ozone precursors that were transported within the smoke plume into Massachusetts. MassDEP's demonstration contains the following evidence to support this conclusion as required by EPA's Exception Events Rule.

- A narrative conceptual model of how the Fort McMurray wildfire led to the ozone exceedances at the Chicopee and Ware monitors, including descriptions of the monitoring locations, the wildfire event, and how the wildfire influenced the monitors.
- A demonstration that the wildfire affected air quality at the Chicopee and Ware monitors in such a way that there exists a clear causal relationship between the wildfire and the elevated ozone concentrations.
- A comparison of the event-influenced concentrations to concentrations at the same monitors at other times.
- Evidence that the event was not reasonably controllable and not reasonably preventable.
- Evidence that the event was caused by human activity that is unlikely to recur at that particular location.
- Documentation that MassDEP followed the public comment process required by EPA's Exceptional Events Rule.

[1] Treatment of Data Influenced by Exceptional Events; Final Rule (81 FR 68216, October 3, 2016).

In 2016, EPA issued guidance for states to use in preparing exceptional event demonstrations.[2] The guidance outlines a 3-tiered approach for addressing the clear causal relationship between a wildfire and observed ozone levels. The tiers are based on the complexity of demonstrating the effect and the amount of evidence needed to satisfy the requirements of the rule.

A Tier 1 analysis may be used if a wildfire clearly influenced monitored ozone levels. The guidance defines the seasonality and/or distinctive level of the ozone as the key factor for determining such clear influence. Specifically, exceedances that are outside of a typical ozone season or that are 5-10 ppb higher than non-event concentrations are clearly distinguishable as event-related according to the guidance. The episode of May 25-26 is in the early part of the ozone season in Massachusetts, and while the concentrations are distinctly above normal for this season, not all are 5-10 ppb above historical normal. Therefore, a Tier 1 analysis is not consistent with the guidance in this case.

A Tier 2 analysis should be used if the effect of a wildfire on a monitor is somewhat less clear and requires more evidence to demonstrate a causal relationship. A Tier 2 analysis would be appropriate for a wildfire that is distant from a monitor, such as the Fort McMurray fire.

The guidance specifies two key factors for establishing a clear causal relationship: (1) the quantity (Q) of emissions from the fire divided by the distance (d) from the monitor (typically known as a Q/d ratio) is $\geq$ 100 tons per day per kilometer (tpd/km); and (2) a comparison of event-related ozone levels with non-event related high ozone levels that shows that the event-related ozone levels are in the 99th percentile for levels in the same year and over the past five years (or are one of the top four ozone maximums within the same year). MassDEP's demonstration shows that while the Q/d ratio is < 100 tpd/km for the Fort McMurray fire, the exceedances on May 25 and 26 are in the 99th percentile for historic levels and are all but one of the top four maximums for 2016.

MassDEP relied on a Q/d analysis performed by the Connecticut Department of Energy and Environmental Protection (CTDEEP) to determine causal effect of the Fort McMurray wildfire on their monitors (see Attachment 1). This analysis is applicable to the Chicopee and Ware monitors because the distances are similar to those for the CTDEEP monitors (i.e., 3190 km average for Chicopee and Ware compared to 3286 km for Stonington). CTDEEP calculated emissions based on the geographical area of the fire, its size, and EPA AP-42 emission factors[3] and determined the distance from the fire using the most distant point in Connecticut (Stonington). CTDEEP used conservative and less conservative approaches, but due to the large

[2] Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations – Final. September 2016. EPA Office of Air Quality Planning and Standards, Air Quality Policy Division, Geographic Strategies Group, Research Triangle Park, NC. https://www.epa.gov/air-quality-analysis/treatment-data-influenced-exceptional-events

[3] AP-42 is EPA's compilation of emission factors and process information for more than 200 air pollution source categories. https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emission-factors

distance, all approaches yielded Q/d values well below the 100 tpd/km value established by EPA for clear causal effect.

MassDEP developed its own evidence consistent with the second factor in a Tier 2 analysis, including:

> *Evidence that the fire emissions affected the monitors*: event vs non-event data plots; and comparative analysis of other ground-level measurements typically associated with smoke (CO, PM, black carbon).
>
> *Evidence that the fire emissions were transported to the monitors*: satellite photographs of smoke plumes and trajectory analysis.

However, since Q/d is less than 100 tpd/km, MassDEP augmented its demonstration with additional evidence consistent with EPA's guidance for a Tier 3 analysis. This evidence includes matching day analysis and a comparison of modelled forecasts with observed levels. Therefore, MassDEP's demonstration is a combination of Tier 2 and Tier 3 approaches.

2. Regulatory Significance

A Design value (DV) is the statistic that is compared to a NAAQS to determine whether the standard is met. Ozone DVs are determined by first ranking maximum 8-hour average concentrations recorded at each monitor for each day during the year. The 4th highest value for each year at each monitor is then averaged over 3 consecutive years to yield the DV for that monitor. Table 1 lists the 4th highest maximum 8-hour average ozone concentrations recorded at Chicopee and Ware (including the days affected by the Fort McMurray wildfire) in the most recent 3-year period (2014-2016) and the resulting DVs for each monitor. The DV for each monitor is 70 parts per billion (ppb), which is the level of the NAAQS. The 2017 Critical Value is the 4th highest ozone concentration that, if met in the 2017 ozone season, would result in a violation of the NAAQS when calculating the 2015-2017 DV.

Table 1 also lists the 4th highest 8-hour average ozone concentrations and DVs for 2016 if values from May 25 and May 26 are removed from the DV calculation. The resultant DVs are 68 ppb at Chicopee and 69 ppb at Ware, and the 2017 Critical Values rise to 72 ppb.

On April 11, 2016 EPA determined that Massachusetts had attained the 75 ppb 2008 ozone NAAQS by the 2015 attainment date.[4] EPA plans to designate states for the 70 ppb 2015 ozone standard by October 1, 2017. Since the DVs are at the level of the 2015 ozone standard with the inclusion of the two days effected by the Fort McMurray wildfires, removing these days will help Massachusetts remain in attainment of the ozone standard.

[4] Determinations of Attainment by the Attainment Date, Extensions of the Attainment Date, And Reclassification of Several Areas for the 2008 Ozone National Ambient Air Quality Standards. Final Rule. April 11, 2016. (FR 81 p.26697 May 4, 2016) https://www.gpo.gov/fdsys/pkg/FR-2016-05-04/pdf/2016-09729.pdf

Table 1
Impact of Event on Design Values – Chicopee and Ware
Values in ppb

	Current Values					May 25-26 Removed		
	2014 4th High	2015 4th High	2016 4th High	**2014-16 Design Value**	2017 Critical Value*	2016 4th High	**2014-16 Design Value**	2017 Critical Value*
Chicopee	65	70	76	**70**	67	71	**68**	72
Ware	68	71	72	**70**	70	70	**69**	72

* Critical value is the 4th highest 8-hour average for 2017 that, if exceeded, would cause a violation of the standard. If the 4th highest 8-hour average for 2017 at the Chicopee and Ware monitors are below this value, the monitors would continue to meet the ozone standards.

3. Area Description

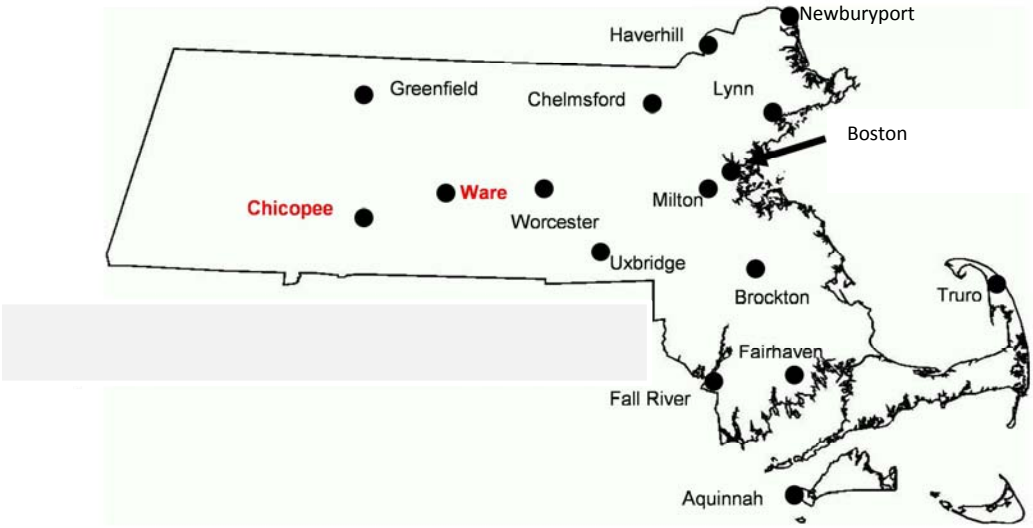
Both the Chicopee and Ware monitors are located in the west-central portion of Massachusetts. The total population in Massachusetts is approximately 6.8 million, and the majority of people live in the more metropolitan areas in eastern Massachusetts, including Boston and its suburbs. West-central areas of the State are more rural, with the exception of the cities of Springfield and Chicopee, which have populations of approximately 155,000 and 57,000, respectively.

The Chicopee monitor is in Hampden County and is located at Westover Air Force Base at an elevation of 272 feet above mean sea level. This area is in the Connecticut River Valley, which is generally oriented in a north-south direction with higher elevations to the east and west. The cities of Holyoke, Chicopee, and Springfield are situated immediately to the south and west of the monitoring station. The areas to the north and east and beyond 10 miles to the south and west are more rural. The monitor represents population exposure on an urban scale (an area of city-like dimensions, on the order of 4 to 50 kilometers), and is part of the Springfield Metropolitan Statistical Area (MSA).

The Ware monitor is in a rural location in the eastern-most part of Hampshire County. The site is located near the south end of the Quabbin Reservoir at an elevation of 1010 feet above mean sea level. Much of the surrounding area is rural; Springfield and Chicopee are the nearest populated areas approximately 15 miles to the southwest. The monitoring station represents population exposure on an urban scale and also is part of the Springfield MSA. **Figure 1** shows the locations of the Chicopee and Ware monitors as well as other monitoring stations in Massachusetts.

Figure 1

MassDEP Ozone Monitoring Network



4. Area Climate

Massachusetts experiences four seasons of weather. The state lies in the prevailing westerlies and often can be subject to colder air masses intruding from northern regions in winter, and experience warmer and occasionally more frequent hot and humid conditions originating from areas to the south and southwest during summer. Eastern areas of the state can be subject to a cooling sea-breeze during the warmer summer months and a milder influence from relatively warmer Atlantic waters during the winter months. Inland areas of the state tend to have more "extreme" conditions relative to coastal locations due to the increasing distance from the Atlantic Ocean's influence.

Summertime weather in the west-central areas of the state typically includes warm daytime temperature levels (70s to low 80s °F) with cooler levels at night (60s °F). However, depending on the location of synoptic-scale weather systems, the area may experience several episodes during the season with temperatures 10-15 °F higher or lower from those that are typical. Most notable are the "Bermuda High" events that can occur over a series of days during the summer months. This scenario is characterized by a large area of high pressure centered off the east coast of the United States. The clockwise circulation around this area results in a south to southwest air flow into Massachusetts bringing hot and humid weather conditions.

5. Characteristics of Area Non-Event Ozone Formation

In general, elevated ozone concentrations occur when there are high levels of ozone "precursor" pollutants – VOCs and NOx – on hot sunny days.

Two primary synoptic meteorological patterns typically trigger high ozone episodes in Massachusetts and can result in episodes having markedly different ozone signatures. One synoptic type, which mainly affects the immediate south coast, Cape Cod, and the Islands, features the Atlantic oceanic anticyclone extending westward well into the interior eastern U.S. A second high pressure center may form within this circulation over the Ohio River Valley area. This results in westerly surface winds over Massachusetts, keeping much of the state's air relatively clean. However, pollution transport from the New York City/New Jersey area eastward across Long Island Sound can bring ozone and ozone precursors to coastal Connecticut, Rhode Island, and extreme south-coastal Massachusetts, including Cape Cod.

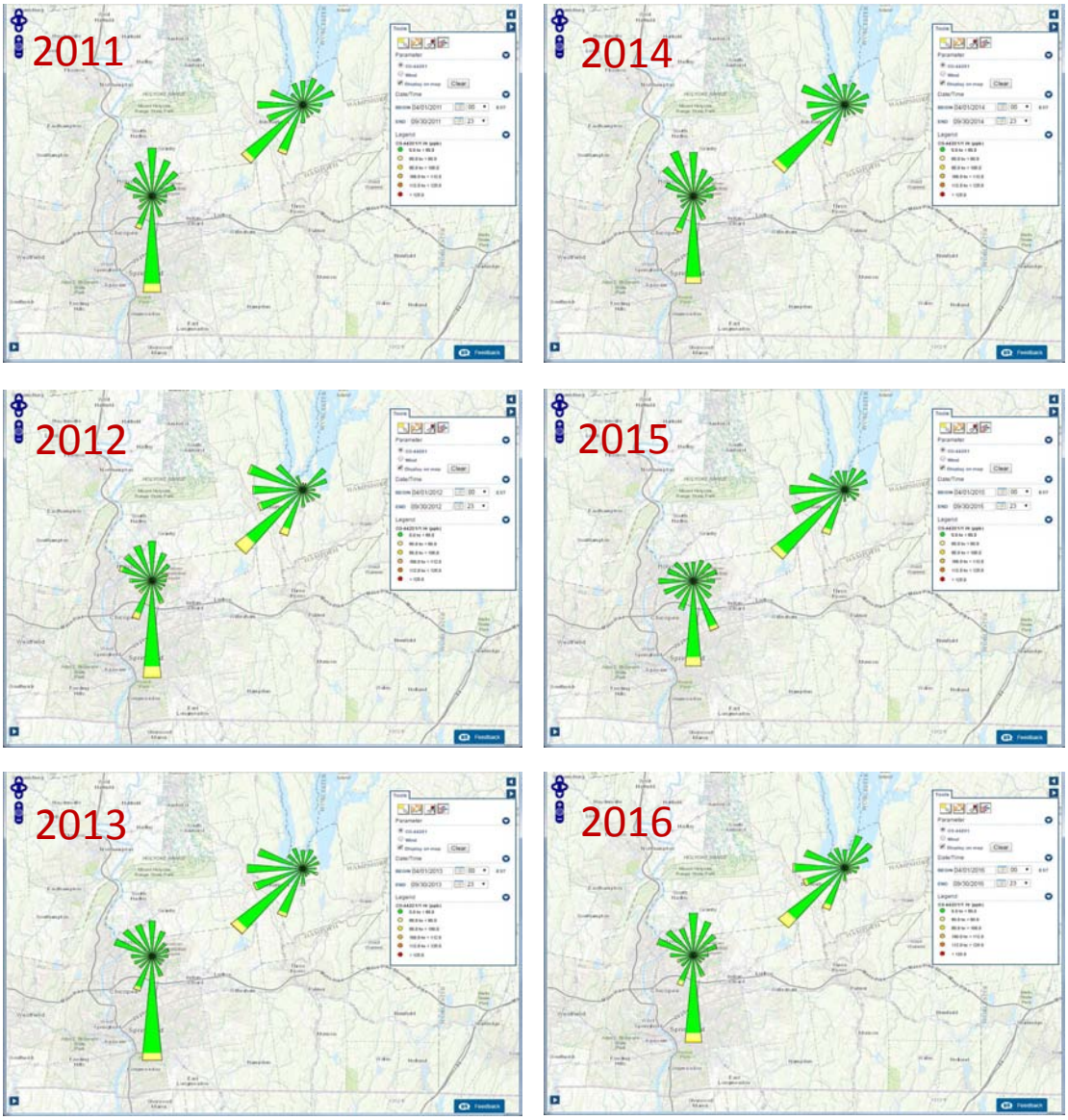
The second episode type occurs when the Atlantic anticyclone has a more northeast-southwest orientation (which, in the previous example, was east-west), with less extension into the interior eastern U.S. This pattern generates a more south-southwesterly flow across Massachusetts, which carries pollutants from the northeast urban corridor northeastward into western and central Massachusetts. This flow keeps the main pollutant plume west of Cape Cod and the south coast, as the southerly breezes there draw in cleaner marine air. In this case, the ozone gradient is reversed from that in the previous example. During this type of episode, the south coast, Cape Cod, and Islands have relatively low ozone, with elevated values across the interior of the state. **Figure 2** presents a series of pollution (ozone) wind roses for the Chicopee and Ware monitoring locations superimposed on an area map. The wind roses represent recorded ozone concentrations along with corresponding wind direction on an annual basis for each of the last 6 years. All of the wind roses indicate a majority of the elevated ozone concentrations (depicted in yellow) coincide with southerly component winds (i.e., south-southeast through southwest, at both monitoring locations).

Over the past 30 years, Massachusetts has experienced an overall decrease in episodes of elevated ozone. The number of exceedance days recorded at monitoring locations across the state is lower in recent years even with EPA's strengthened ozone standards. Only one county – Dukes (Martha's Vineyard) – was designated non-attainment for the 2008 ozone standard. However, in 2016, EPA determined that the entire state had attained the 2008 standard by the attainment date of July 20, 2015.[5] Massachusetts monitors now show that the entire state also meets the more stringent 2015 standard.

[5] Determinations of Attainment by the Attainment Date, Extensions of the Attainment Date, and Reclassification of Several Areas for the 2008 Ozone National Ambient Air Quality Standards. Environmental Protection Agency (EPA). Final rule. April 11, 2016. (FR81, May 4, 2016 p. 26697) https://www.epa.gov/sites/production/files/2016-04/documents/20160411fr.pdf

Figure 2

Ozone Concentration Wind Roses for Chicopee and Ware



Annual ozone wind roses for Chicopee and Ware monitoring sites for years 2011-2016. Wind rose data indicates relative frequency of wind direction and levels of ozone associated with each direction. Elevated levels of ozone are depicted in yellow and are generally associated with southerly component winds (south-southeast through southwest) in each of the years.

6. Wildfire Description

On May 1, 2016, a wildfire of unknown origin began southwest of Fort McMurray, Alberta, Canada. The fire quickly gained in size and two days later, moved through the community of Fort McMurray forcing the largest wildfire evacuation in Albertan history. [6] The wildfire continued to grow in size spreading across northern Alberta and into Saskatchewan. [7] Firefighting personnel from across Alberta as well as from other Canadian provinces and the Canadian military responded to help battle the wildfire.

The rapid growth and duration of the wildfire was aided by unusually hot and dry weather conditions over northern areas of Alberta. The situation worsened during the first week as winds began gusting at speeds exceeding 40 mph. The fire was not officially declared under control until more than two months later on July 5 after spreading across nearly 1.5 million acres. Approximately 2400 homes and other buildings were destroyed. It is the costliest disaster in Canadian history. [8]

Smoke from the wildfire began to affect the surrounding area including the community of Fort McMurray almost immediately. The continued rapid development and increased areal coverage of the fire enhanced the associated smoke plumes, and by May 7 smoke was affecting not only areas of Alberta but also Saskatchewan, Manitoba, and the north-central portion of the U.S. As the fire continued to burn, satellite data indicated that smoke plumes advanced and affected even larger portions of Canada and the U.S. for much of the month of May. **Figure 3** presents visible satellite images showing the wildfire smoke plume on select days during the May 4-19 period.

[6] *Parsons, Paige (May 4, 2016). "Fort McMurray residents flee in the largest fire evacuation in Alberta's history". Edmonton Journal.*
[7] *Parsons, Paige (May 19, 2016). "Fort McMurray fire grows to 505,000 hectares as it crosses into Saskatchewan". Edmonton Journal.*
[8] *Romero, Diego (July 7, 2016). "Fort McMurray wildfires damage cost $3.58 billion". CTV Edmonton.*

Figure 3

Satellite Imagery of the Fort McMurray Wildfire Smoke Plume

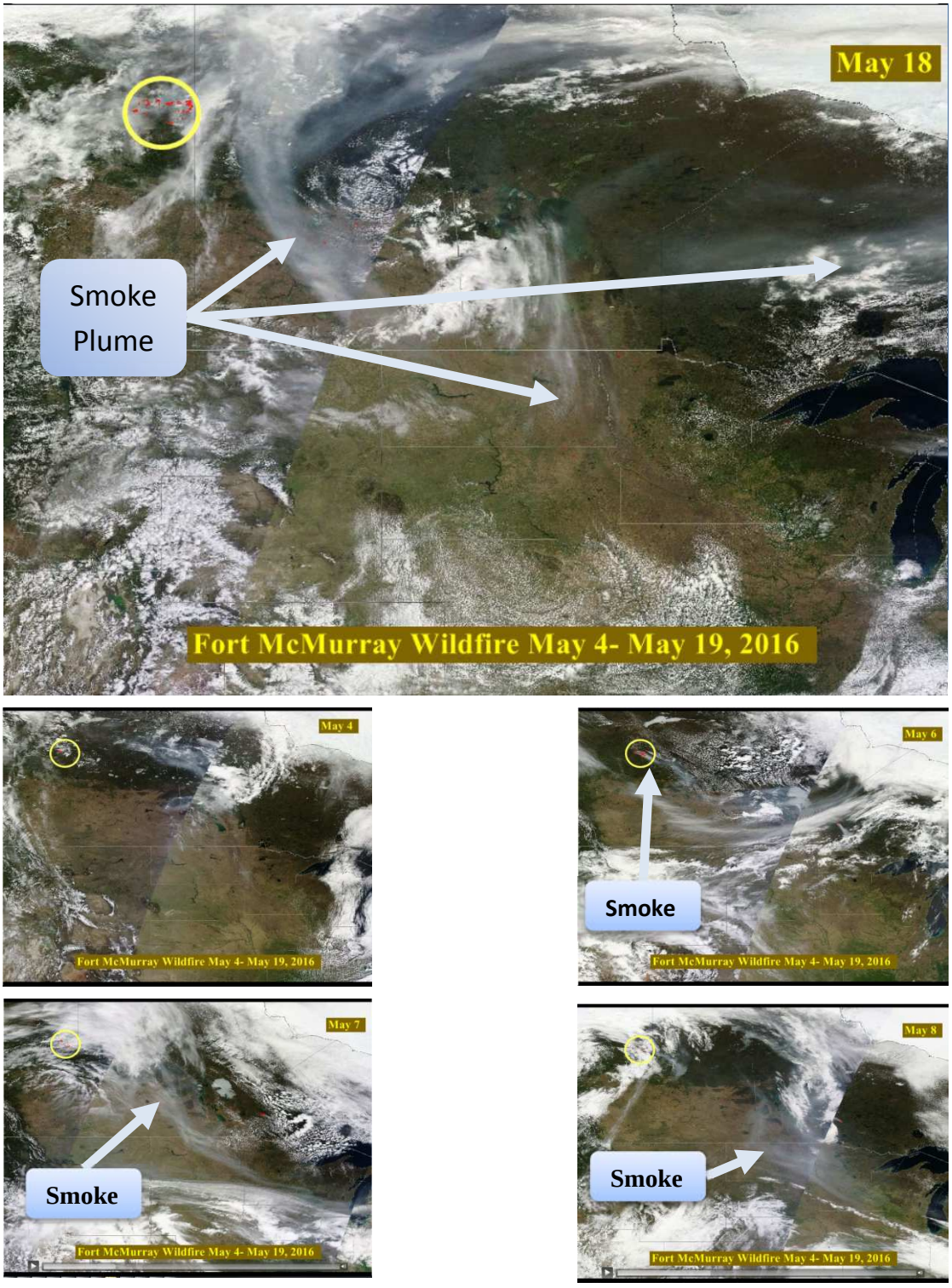
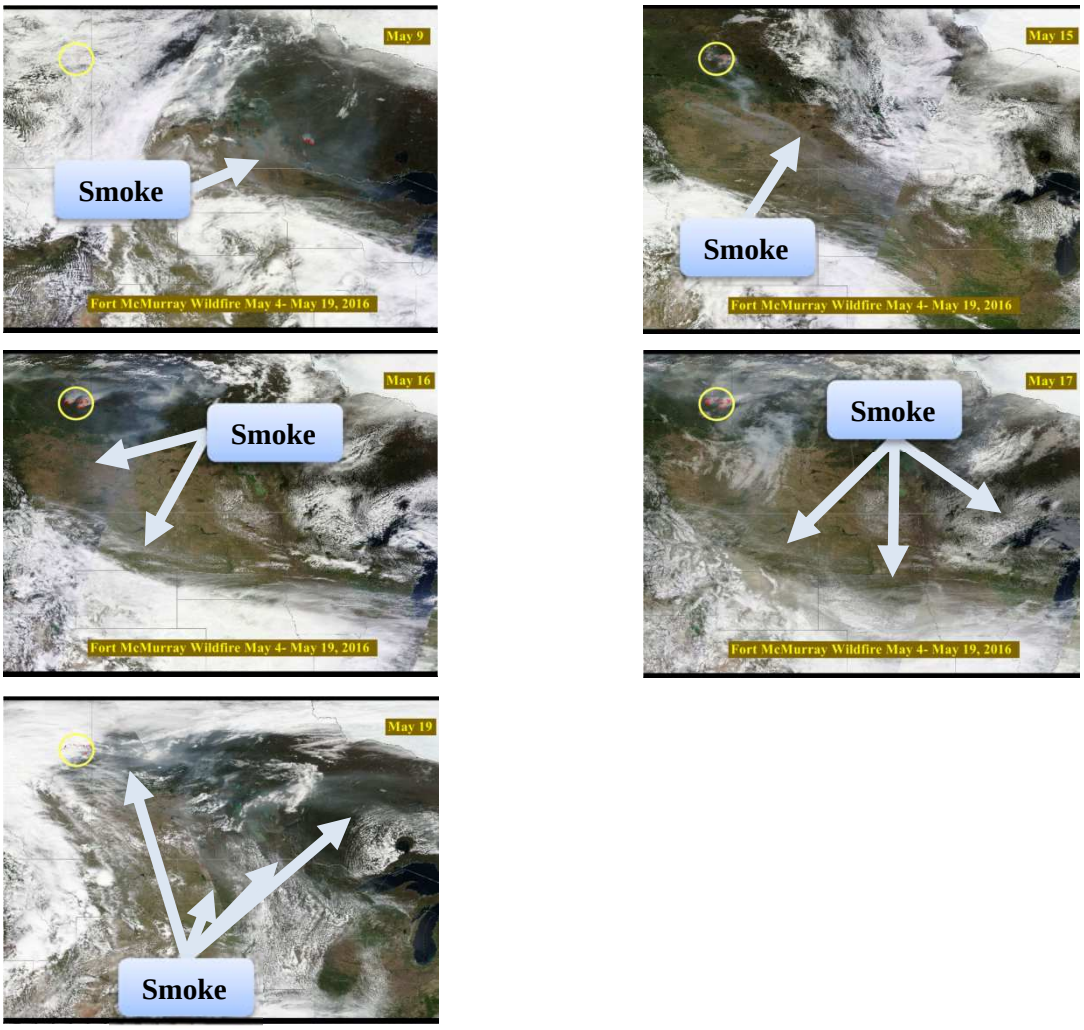


Figure 3 (continued)

Satellite Imagery of the Fort McMurray Wildfire Smoke Plume



Visible satellite pictures showing north-central U.S. and western Great Lakes region with smoke plume from Fort McMurray wildfire. Smoke was visible shortly after ignition on May 4 and continued to build up throughout the region for more than 2 weeks. Imagery from NASA's Earth Observing System Data and Information System (EOSDIS) at https://worldview.earthdata.nasa.gov/.

7. Conceptual Model of Ozone Formation from the Fort McMurray Wildfire

The relationship between wildfire smoke and elevated ozone levels is documented in a number of scientific articles from peer-reviewed journals.[9] These articles contain examples of wildfire smoke plumes enhancing levels of ozone nearby, as well as augmentation of levels far from the fire due to buildup and long-range transport of ozone precursors within the plume. Photochemical modeling results simulating wildfire smoke effects on ozone also provide evidence of enhancement.

Smoke from biomass burning contains ozone precursors such as nitrogen oxides (NOx) and non-methane hydrocarbons (NMHCs) (McKeen et al., 2002; Jaffe et al., 2008). Previous observational studies have shown that smoke from biomass burning can enhance the formation of ozone under a variety of conditions (e.g., Hobbs et al., 2003; Junquera et al., 2005; Pfister et al., 2006). Ozone enhancement due to biomass burning is highly variable and depends on a number of factors including fuel type, combustion efficiency, and available solar radiation (Jaffe and Wigder, 2012). In addition, ozone enhancement associated with biomass burning can take place both immediately downwind of a fire and after long-range smoke transport. Junquera et al. (2005) found ozone enhancements of up to 60 ppb within 10 km of fires in eastern Texas. Using ozonesondes, Morris et al. (2006) found a 25–100 ppb increase in aloft ozone concentrations over Texas due to long-range transport of smoke from wildfires in Canada and Alaska. In the analysis of a November 2009 smoke plume in California, Akagi et al. (2012) found that "despite occurring approximately one month before the winter solstice, the plume was photochemically active and significant amounts of ozone formed within a few hours", demonstrating that ozone enhancement due to smoke can take place in the cool season when ozone concentrations are typically lower. Conversely, in some cases, ozone concentrations were shown to be suppressed near wildfires, possibly because of thick smoke obstructing incoming UV radiation and/or titration of ozone due to high NOx concentrations in the smoke plume (Bytnerowicz et al., 2010; Stith et al., 1981).

Previous studies have also shown that fires contributed to exceedances of the NAAQS for 8-hour ozone (Jaffe et al., 2004; Junquera et al., 2005; Bein et al., 2008). And, using photochemical model simulations, Pfister (2008) found 10–15 ppb increases in ozone near fires in Northern California over the September 1-20, 2007, period and near fires in Southern California over the October 15-30, 2007, period, concluding that "intense wildfire periods frequently can cause ozone levels to exceed current health standards." In addition, the EPA previously agreed to a request from the California Air Resources Board (CARB) and the Sacramento Metropolitan Air

[9] Much of the wording and examples given in this section are from the previously approved KDHE Exceptional Event Demonstration – see original document for specific citations. *State of Kansas Exceptional Event Demonstration Package April 6, 12, 13, and 29, 2011; KDHE; November 27, 2012 (https://www.epa.gov/sites/production/files/2015-05/documents/kdhe_exevents_final_042011.pdf)*

Quality Management District (SMAQMD) to exclude exceedances of the NAAQS for 1-hour ozone concentrations due to emissions from biomass burning under the Exceptional Events Rule. EPA also approved a 2012 request from the Kansas Department of Health and Environment (KDHE) to exclude several 8-hour average ozone concentrations in April 2011 that were in exceedance of the NAAQS due to numerous fires in areas upwind of monitoring locations. In these cases, CARB, SMAQMD, and KDHE used a weight-of-evidence approach similar to the approach used for this Exceptional Events demonstration—including analysis of air quality and meteorological data, satellite imagery, and air parcel trajectories – to show that smoke from wildfires resulted in ozone exceedances in their respective regions.

Based on its considerable size, significant amounts of NOx and VOCs were emitted from the Fort McMurray wildfire. On May 18, the plume from the Fort McMurray wildfire began dispersing toward the U.S. upper Midwest and Great Lakes region where it became trapped due to subsidence and light winds associated with a large area of high pressure. This high pressure area was the dominant meteorological feature in the Midwest area of the country in the following days (May 19-23) and then began to shift eastward on May 24. Weather conditions for the area included seasonable temperature levels accompanied by generally light winds during the period. **Figure 4** presents National Weather Service (NWS) Surface Analysis Maps for May 18-24. Each map shows locations of meteorological features including centers of high and low pressure, frontal systems, and current weather observations from NWS reporting stations. The area of high pressure over the Great Lakes region/upper Midwest and its transition slowly eastward is evident in Figure 4.

Figure 4

Surface Weather Analysis Showing Large High Pressure System Across Upper Midwest and Great Lakes Region of U.S.

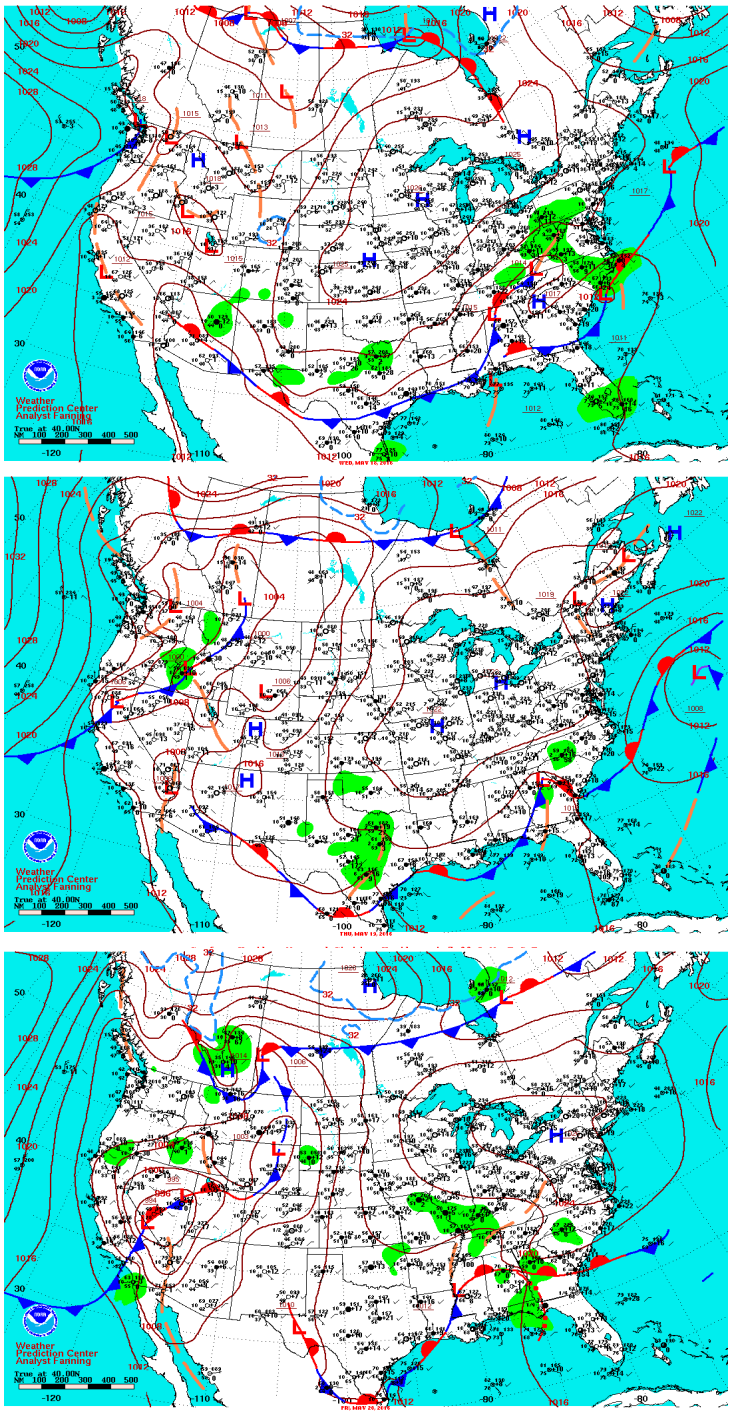
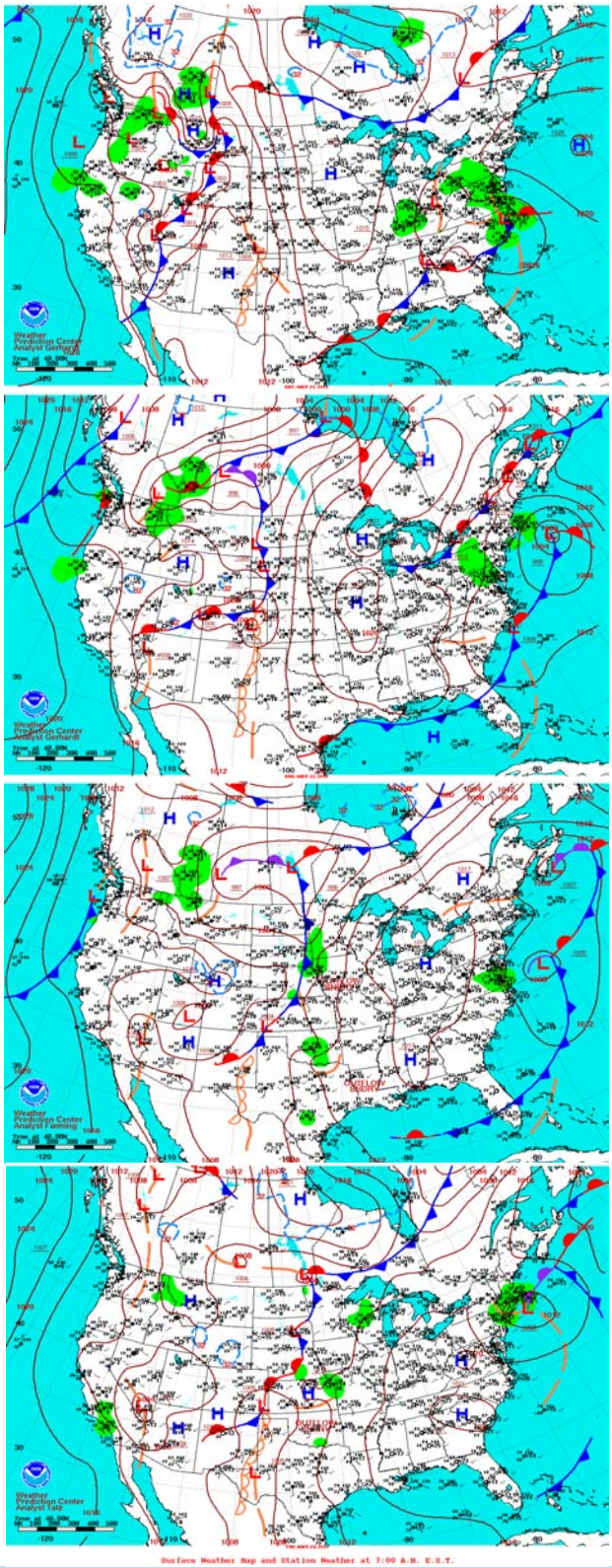


Figure 4 (continued)



May 21, 2016

May 22, 2016

May 23, 2016

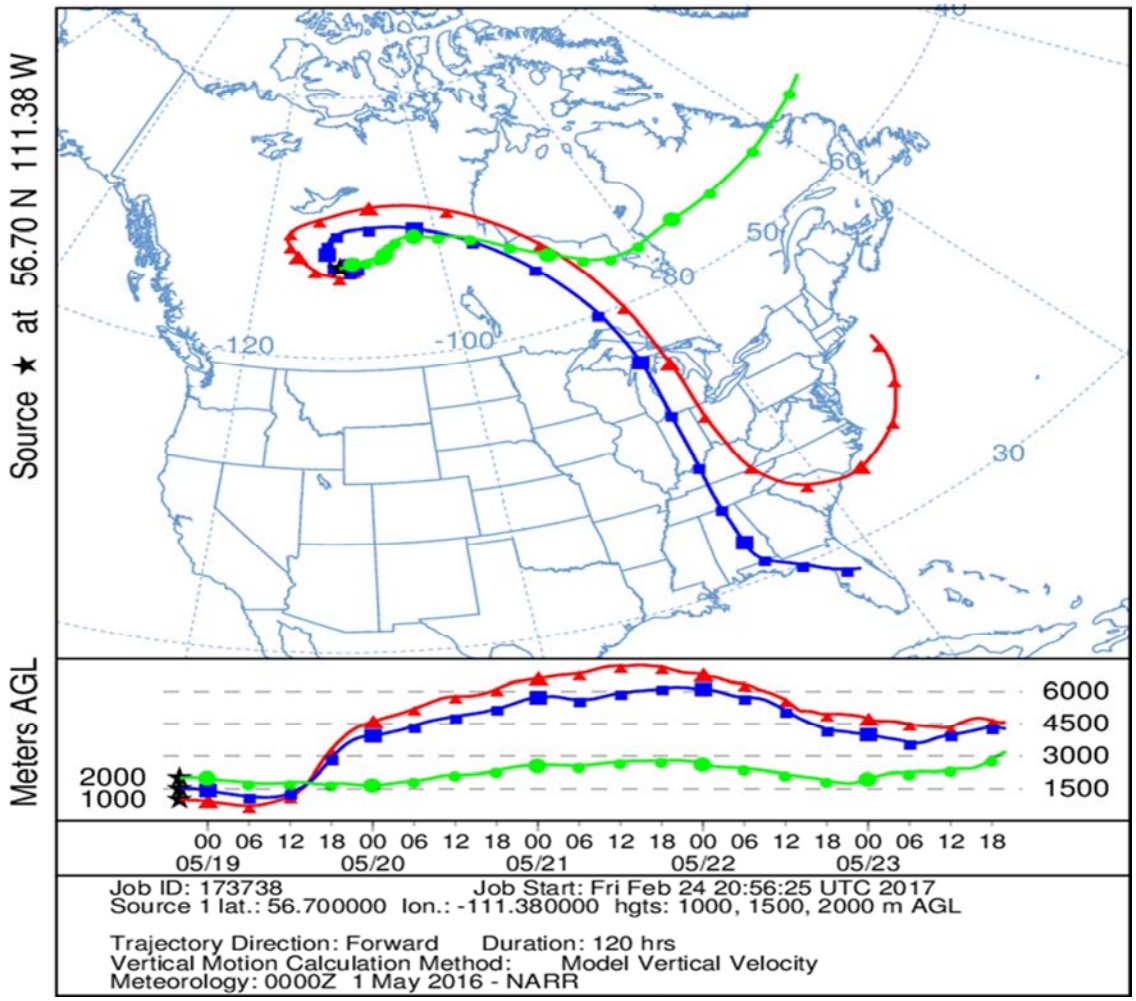
May 24, 2016

To show that the wildfire plume could be transported from its source in Alberta to the Great Lakes region, a forward trajectory analysis was executed using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (model initialized and run by CTDEEP). This model calculates the position of parcels of air over time based on meteorological data. Transport at different altitudes can be specified for simultaneous analysis and display. This allows for better determination of a consistent flow in ascending levels of the atmosphere or if the flow changes direction and/or speed with height. Increments of six hours in each trajectory are indicated by a point on the trajectory line with larger markers indicating every 24-hours. A longer space between points implies faster wind speeds. For this episode, a 120-hour forward trajectory starting on May 18 at the 1000m, 1500m, and 2000m levels was generated to show where air parcels would likely travel.

Figure 5 presents the HYSPLIT model results and indicates that air parcels on May 18 at the higher 2000m level (green line) may have traveled in a more easterly direction remaining over Canada. However, the model clearly indicates that parcels at the 1000m (red line) and 1500m (blue line) levels would likely have been transported from the Fort McMurray area to the Great Lakes area arriving on or about May 21 (denoted by larger markers over Michigan). With surface high pressure over the region, particles within these parcels would likely have become trapped due to light winds and limited mixing conditions associated with the high pressure system.

Figure 5

HYSPLIT Model 120-hr Forward Trajectories – May 18, 2016



HYSPLIT model results for 120-hour forward trajectory analysis. Levels shown are 1000m (red line), 1500m (blue line), and 2000m (green line) with markers indicating 6-hour interval. Results indicate air parcels at the 1000m and 1500m levels originating in the Fort McMurray area on May 18 likely would have traveled toward the Great Lakes area arriving on or about May 21 (denoted by larger 72-hour marker over Michigan).

The National Oceanic and Atmospheric Administration (NOAA) provides the Hazard Mapping System (HMS)[10] fire and smoke plume analysis from environmental satellite data. **Figure 6** presents these images showing that the satellite detected smoke plume (outlined in gray) resided over Canada and the U.S. upper Midwest on May 18 and proceeded to change orientation and size while slowly moving eastward through May 24.

[9] Hazard Mapping System Fire and Smoke Product (http://www.ospo.noaa.gov/Products/land/hms.html)

Figure 6

Location of Smoke Plume as Detected by HMS Satellite

NOAA's Hazard Mapping System Fire and Smoke Product (http://www.ssd.noaa.gov/PS/FIRE/hms.html) May 18-24: Fire (red points) and smoke data (shaded in gray) detected by satellite each day is displayed on map of North and Central America. Images show plume from Fort McMurray wildfire across central Canada and upper Midwest of U.S. on May 18. Plume then continues to expand and change shape while slowly moving eastward during successive days.

Figure 6 (continued)

Location of Smoke Plume as Detected by HMS Satellite

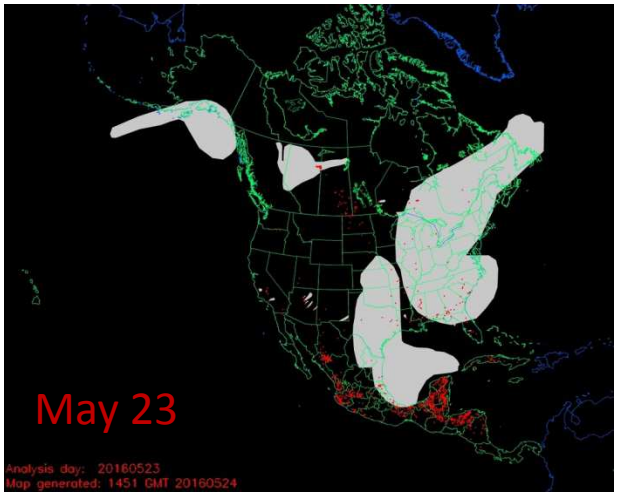


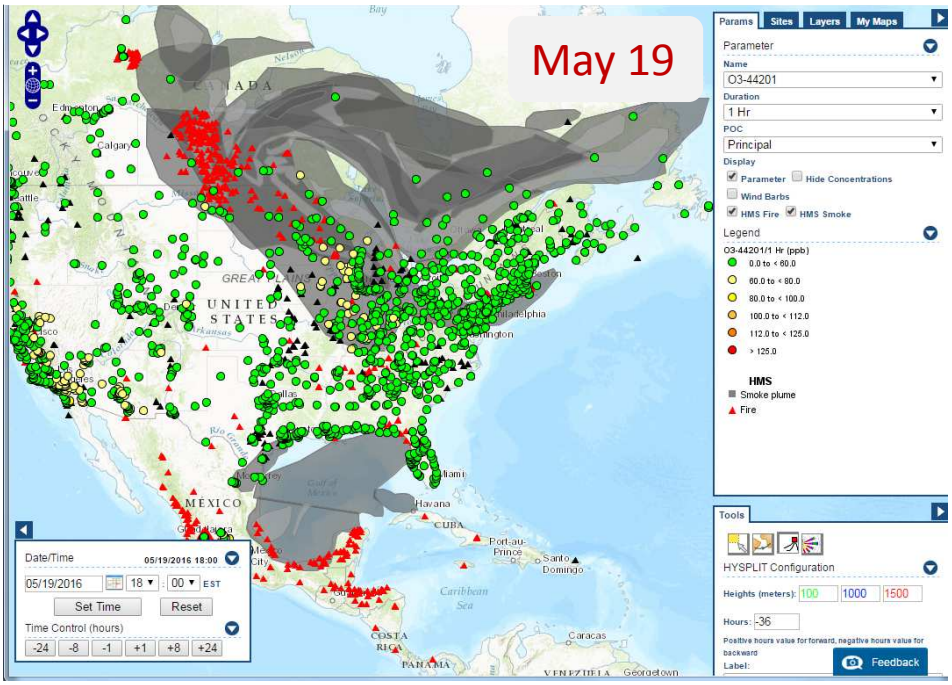
Figure 6 (continued)

Location of Smoke Plume as Detected by HMS Satellite

During this same time period, elevated ozone levels were observed in this region even though meteorological conditions were not conducive to elevated ozone development (generally light and variable winds and seasonable temperature levels associated with the large area of high pressure). **Figure 7** presents the HMS smoke and fire data along with the late afternoon/early evening observed ozone levels for each day from May 19-24. In each figure, an ozone observing station is represented by a green or yellow point with the yellow point indicating an elevated ozone level based on EPA's Air Quality Index (AQI). The data in the figures indicate that the area of elevated ozone expanded in size over the period and slowly moved eastward in conjunction with the wildfire plume. This type of pattern would indicate that ozone precursors from the wildfire were transported within the smoke plume and resulted in higher ozone levels than would have been expected with concurrent meteorological conditions.

Figure 7

Late Afternoon/Early Evening Ozone Concentrations with Wildfire Locations and Smoke Plumes – May 19-24, 2016



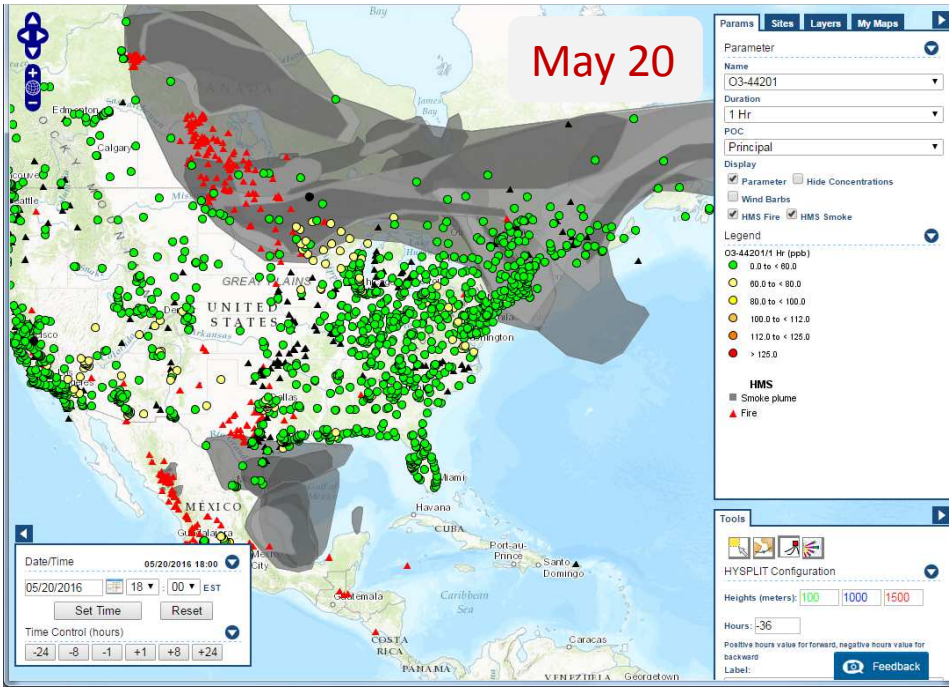
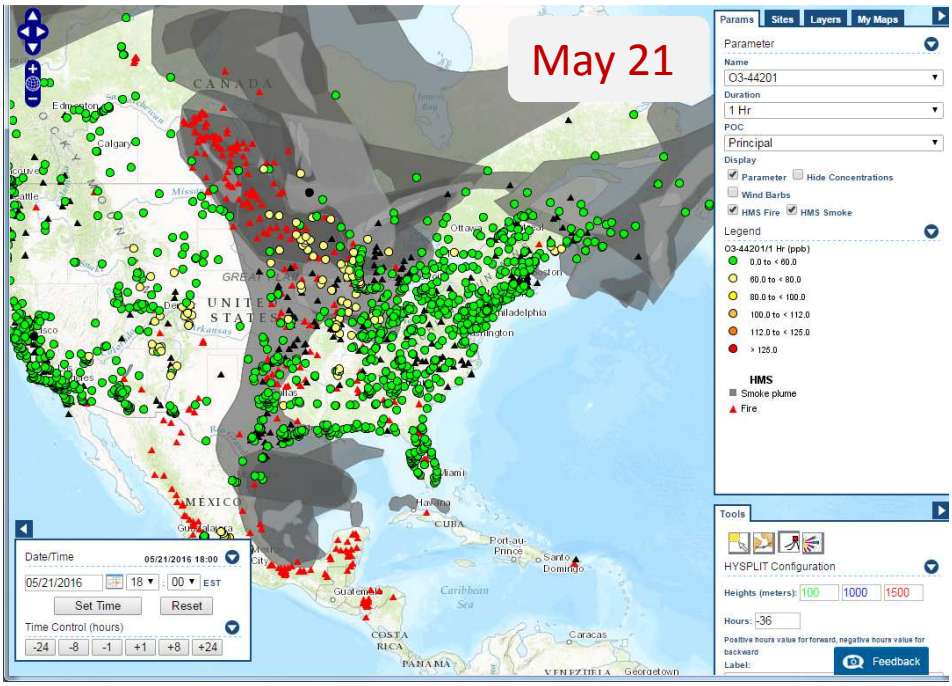


Figure showing location of fires and smoke (from HMS fire and smoke data) along with late afternoon ozone levels. Elevated ozone levels (yellow points) evident in upper Midwest/western Great Lakes region. Display generated via AirNow-Tech (http://www.airnowtech.org/)

Figure 7 (continued)

Late Afternoon/Early Evening Ozone Concentrations with Wildfire Locations and Smoke Plumes – May 19-24, 2016



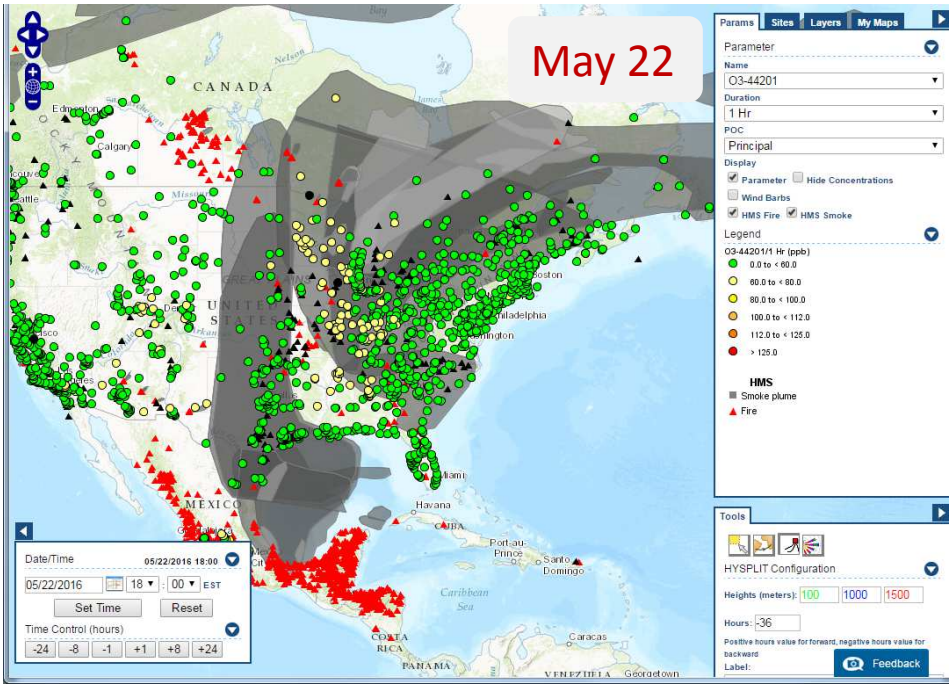


Figure showing location of fires and smoke (from HMS fire and smoke data) along with late afternoon ozone levels. Elevated ozone levels (yellow points) evident in Midwest/western Great Lakes region. Display generated via AirNow-Tech (http://www.airnowtech.org/)

Figure 7 (continued)

Late Afternoon/Early Evening Ozone Concentrations with Wildfire Locations and Smoke Plumes – May 19-24, 2016

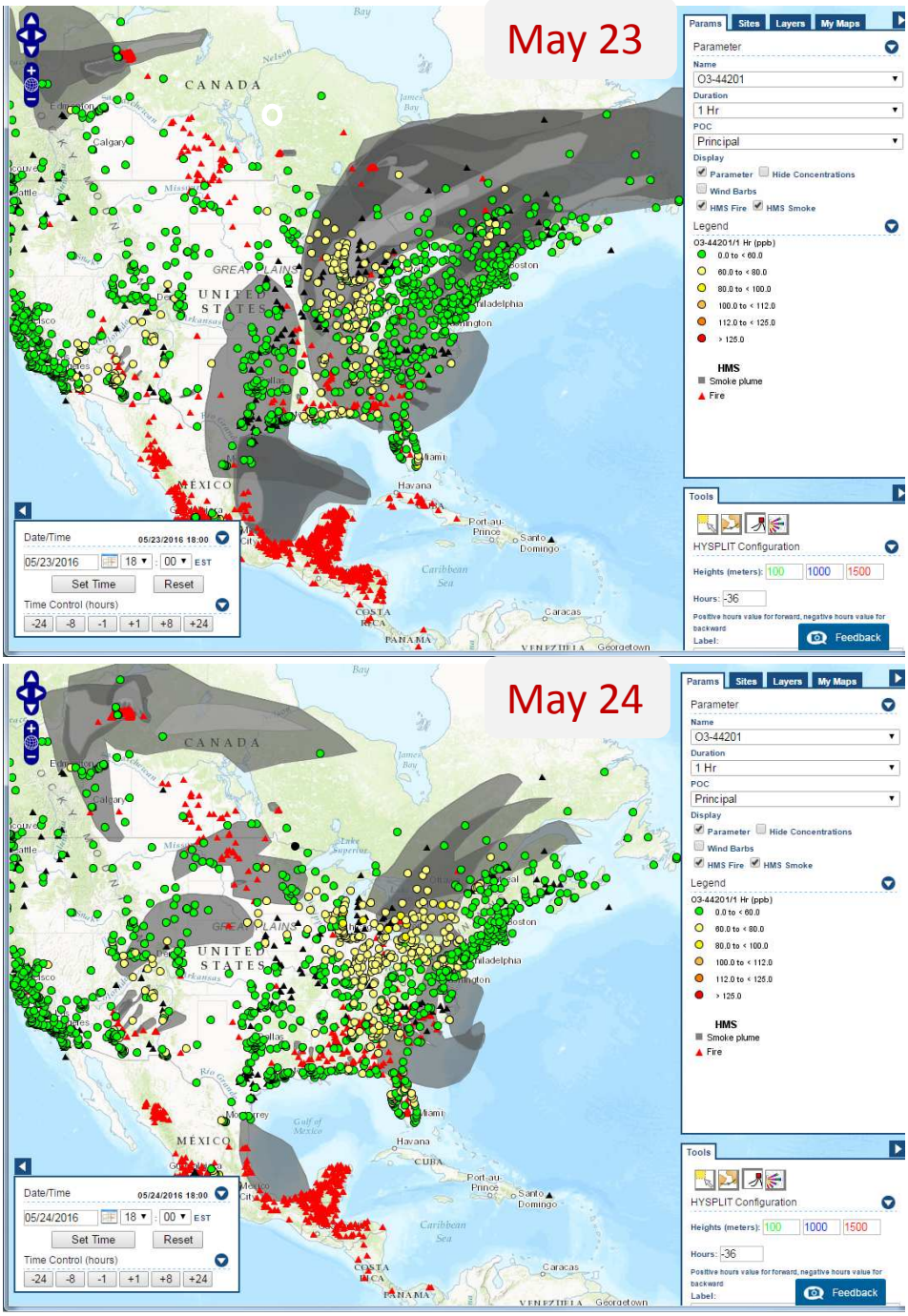


Figure showing location of fires and smoke (from HMS fire and smoke data) along with late afternoon ozone levels. Elevated ozone levels (yellow points) evident in Midwest/Great Lakes region. Display generated via AirNow-Tech (http://www.airnowtech.org/)

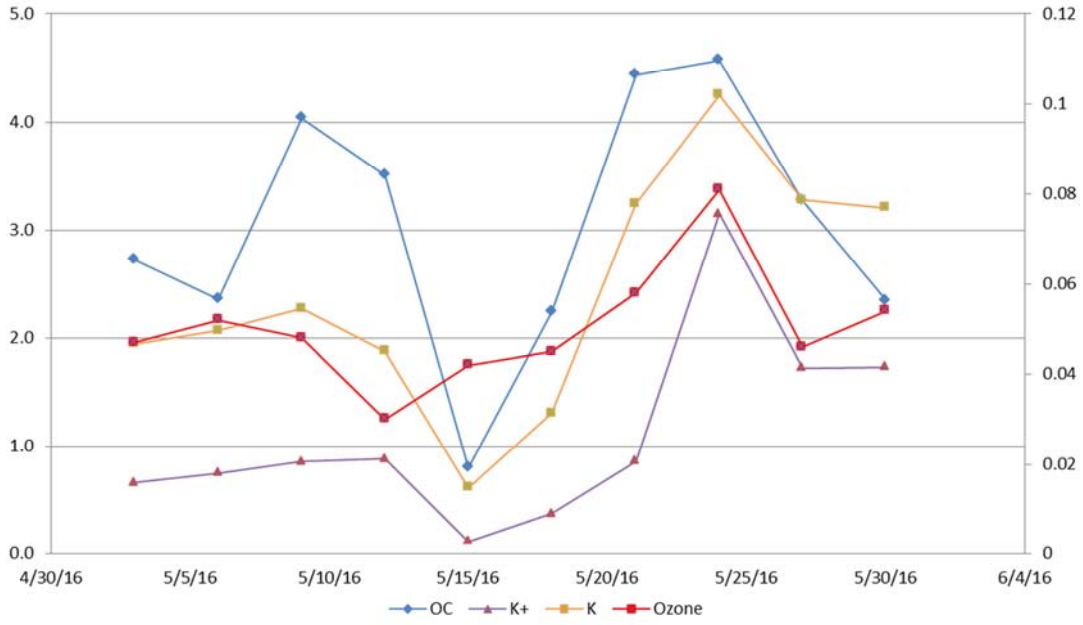
To further illustrate that the plume was crossing the Great Lakes area during this time period, data from EPA's PM2.5 Chemical Speciation Monitoring Network (CSN) were analyzed. Both organic carbon (OC) and potassium (K, K+) are closely associated with wildfire emissions. These data are collected at various locations on an every 3-day schedule by the CSN. **Figure 8** presents the 3 monitoring locations from which OC and K/K+ data were retrieved for analysis. Locations in western Michigan, eastern Michigan, and west-central New York state were chosen to represent the area where previously shown modeled transport of the plume was likely to occur and where both HMS data and visible satellite images indicate the wildfire plume.

Figure 8 also presents data plots from each of the 3 monitoring locations showing trends of OC and K/K+ during May 2016. In each plot, an increase in levels of these species is evident with the May 21 and May 24 samples, which would coincide with the plume over the area. Concurrent maximum 8-hour ozone concentrations are also plotted in each figure showing elevated ozone levels at these locations during this same time. The elevated levels of OC and K/K+ observed at these ground monitoring stations are further evidence that the plume from the Fort McMurray wildfire was affecting the Great Lakes area during this period and moving eastward into New York.

Figure 8

Chemical Speciation Network (CSN) Data

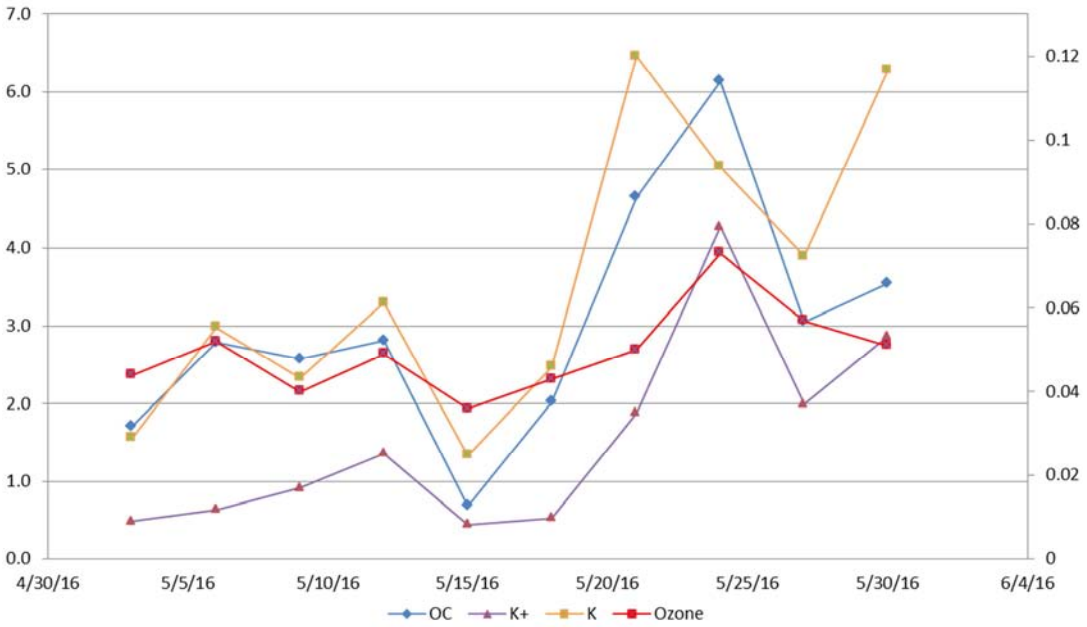
Chemical Speciation Network (CSN) Site Locations Analyzed for
Organic Carbon (OC), Potassium (K/K+), and Ozone Data



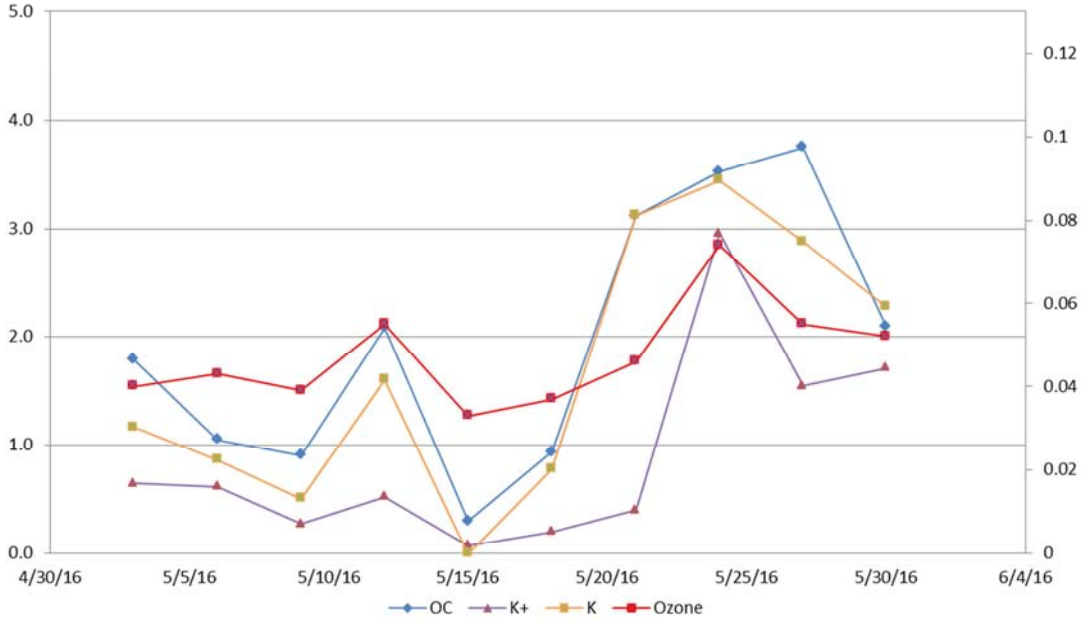
Grand Rapids, Michigan
Daily Organic Carbon (OC), Potassium (K/K+), and Max 8-hr Ozone May 2016

Figure 8 (continued)

Chemical Speciation Network (CSN) Data



Allen Park, Michigan Daily Organic Carbon (OC), Potassium (K/K+), and Max 8-hr Ozone Data May 2016



Rochester, NY Daily Organic Carbon (OC), Potassium (K/K+), and Max 8-hr Ozone Data May 2016

Chemical Speciation Monitoring Network (CSN) trend data from western Michigan, eastern Michigan, and west-central New York all indicate increases in levels of species associated with wildfire smoke May 21-24. Concurrent elevated levels of ozone are also indicated.

The unexpected nature and uniqueness of this elevated ozone scenario can be further demonstrated by comparing predictions from the NOAA CMAQ model[11] (commonly used to forecast ozone levels), and the actual observed levels of ozone on those days because the NOAA CMAQ model does not account for the influence of the wildfire. While air quality models can both under- and over-predict concentration levels, it would be more unusual for a multi-day series of under- or over-predictions by a significant margin (i.e., 10 ppb or greater). **Figure 9** presents levels of bias (i.e., the difference between modeled ozone concentrations and those that were actually observed by monitors) for May 19-24. Data presented in these figures indicate the model forecasts under-predicted the observed levels in the area affected by the plume every day during the period – in some cases by 10 ppb or more. This consistency and degree of negative bias in the model is likely evidence of the influence of the smoke plume on observed area ozone concentrations.

Figure 9

Model Predicts Low Ozone in the Upper Midwest May 19-23

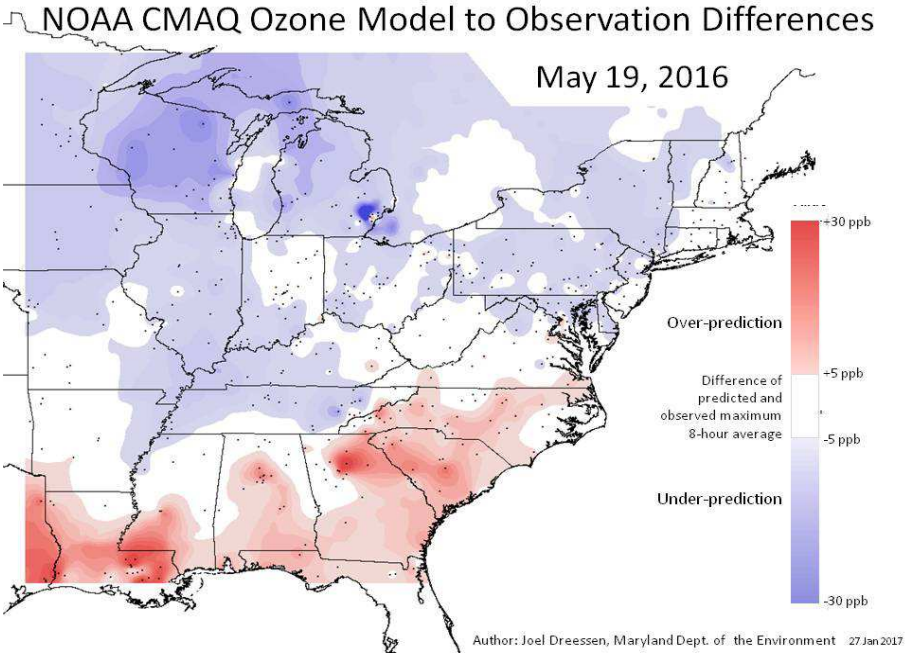


Figure shows CMAQ model bias compared to observed ozone levels. Blue shadings indicate degree of model under-prediction as smoke influences ozone levels across the Great Lakes region. Image courtesy of Joel Dreessen, Maryland Department of Environmental Protection (MDDEP).

[11] Community Modeling and Analysis System (CMAQ) https://www.cmascenter.org/cmaq/

Figure 9 (continued)

Model Predicts Low Ozone in the Upper Midwest May 19-23

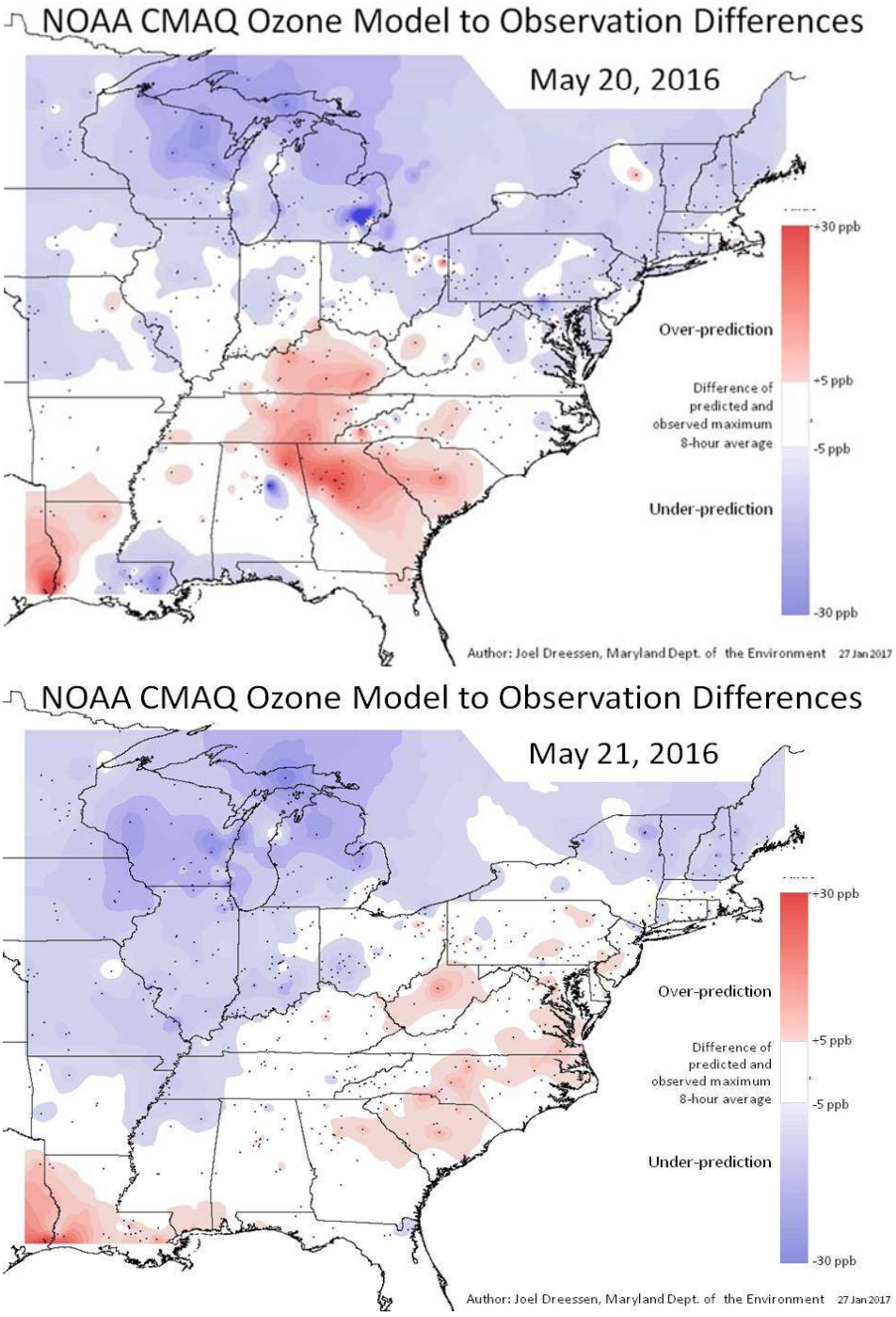
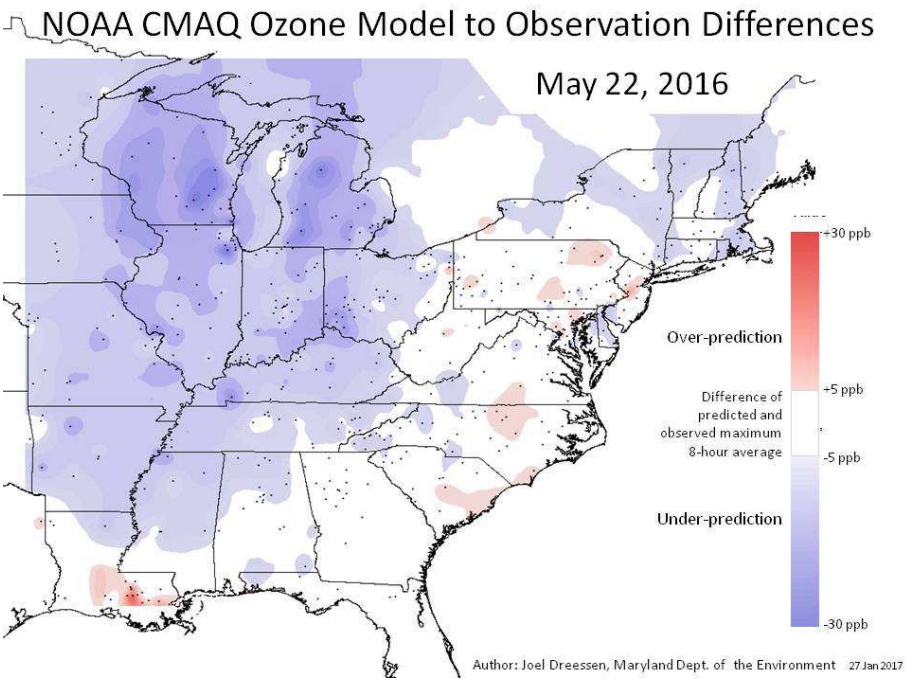


Figure showing CMAQ model bias to observed ozone levels. Blue shadings indicate degree of model under-prediction as smoke influences ozone levels across the Great Lakes region. Image courtesy of Joel Dreessen, Maryland Department of Environmental Protection (MDDEP).

Figure 9 (continued)

Model Predicts Low Ozone in the Upper Midwest May 19-23



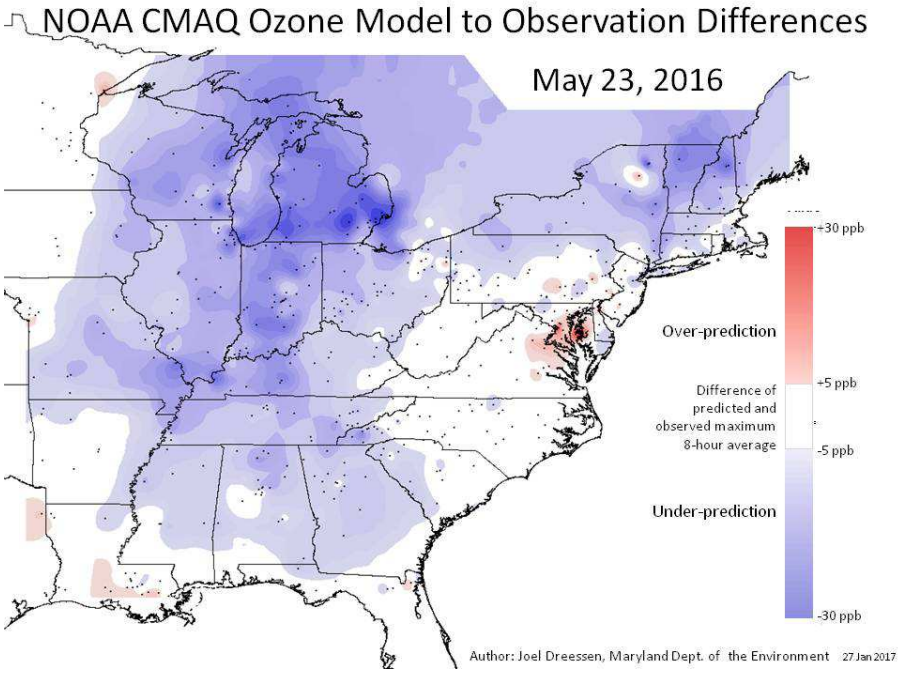


Figure showing CMAQ model bias to observed ozone levels. Blue shadings indicate degree of model under-prediction as smoke influences ozone levels across much of the east-central U.S. and parts of the northeast. Image courtesy of Joel Dreessen MDDEP.

Figure 9 (continued)

Model Continues to Predict Low Ozone as Plume Spreads – May 24

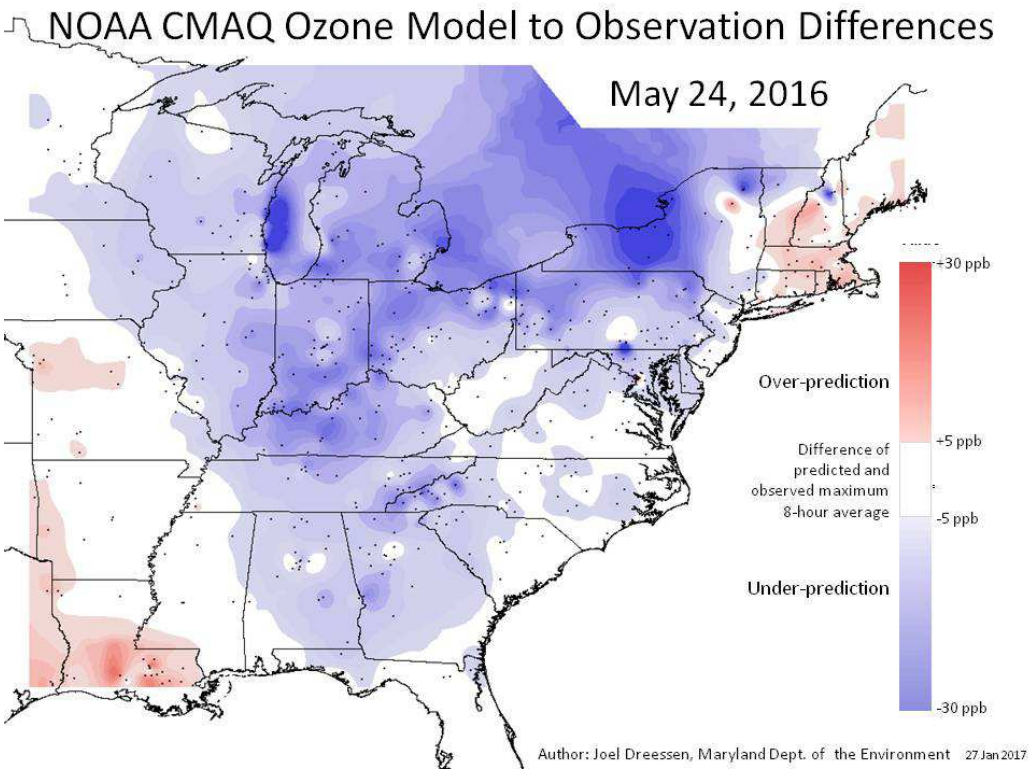


Figure showing CMAQ model bias to observed ozone levels. Blue shadings indicate degree of model under-prediction as smoke influences ozone levels across much of the east-central US and parts of the northeast. Image courtesy of Joel Dreessen MDDEP

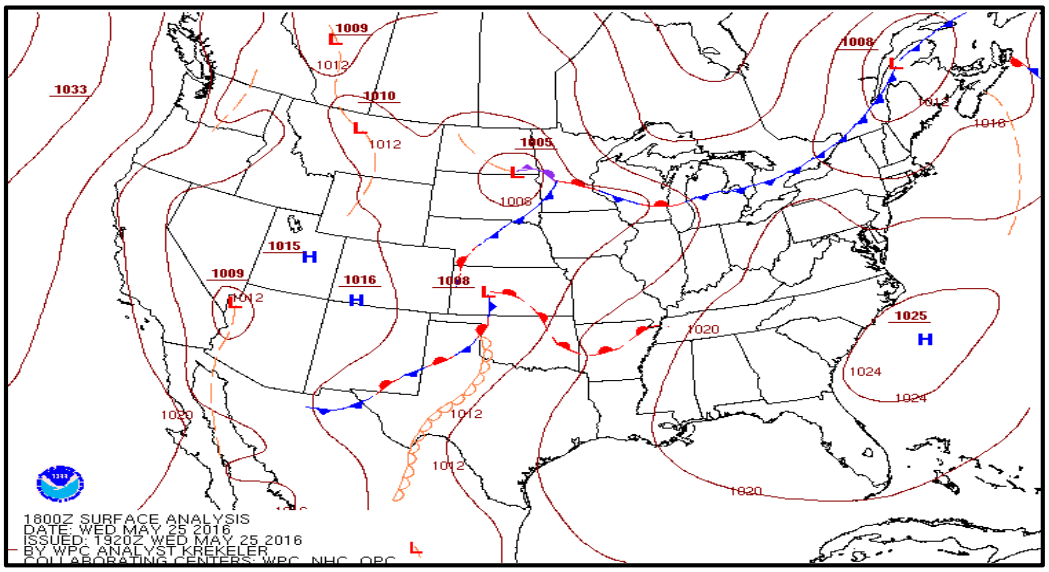
Elevated ozone levels began affecting much of the northeast U.S. on May 25 and continued through May 26 at the same time as HMS satellite data show the plume arriving in the region. Ozone levels in most of New England up to the Canadian border, New York State, Pennsylvania, New Jersey, Maryland, and Delaware were dramatically affected. On May 25, this impact included high numbers of exceedances of the 70 ppb ozone standard throughout the northeast – examples for several states are listed below.

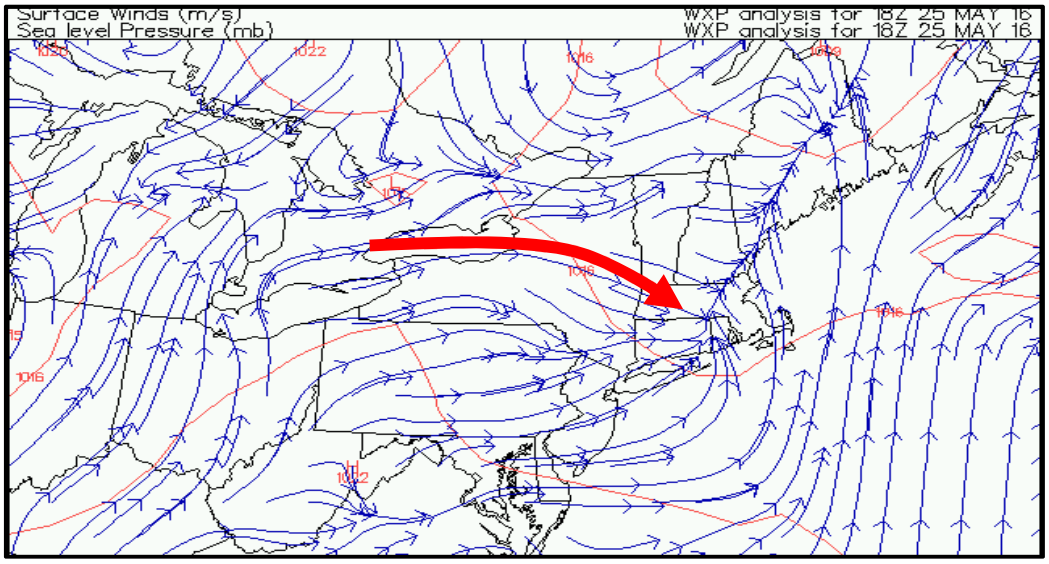
NJ – 16 of 17 monitors exceeded
NY – 29 of 30 monitors exceeded
CT – 11 of 12 monitors exceeded
RI – 3 of 3 monitors exceeded
MA – 9 of 15 monitors exceeded (with 3 additional monitors reaching the standard)

As was the case in the upper Midwest and Great Lakes region in the days prior, meteorological conditions in the northeast on May 25 and 26 were not favorable for the production of such elevated levels. **Figures 10 and 11** present NWS surface analysis for May 25 and 26, respectively, including an analysis of surface winds in the northeast U.S. The data show flows near the surface were generally out of the west and west-northwest across western and central areas of Massachusetts on May 25. Surface winds were quite light and variable on May 26 due to the position of a cold front over central and western Massachusetts as depicted in the surface analysis.

Figure 10

Surface Analysis Showing Generally West to West-Northwest Flow into Western Massachusetts – May 25, 2016

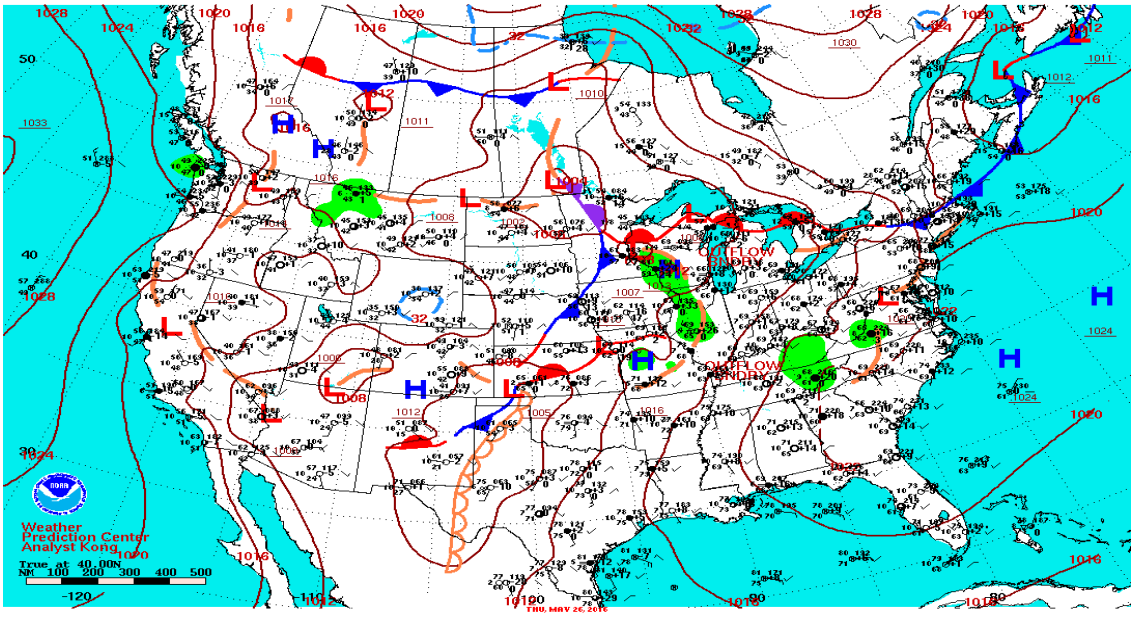


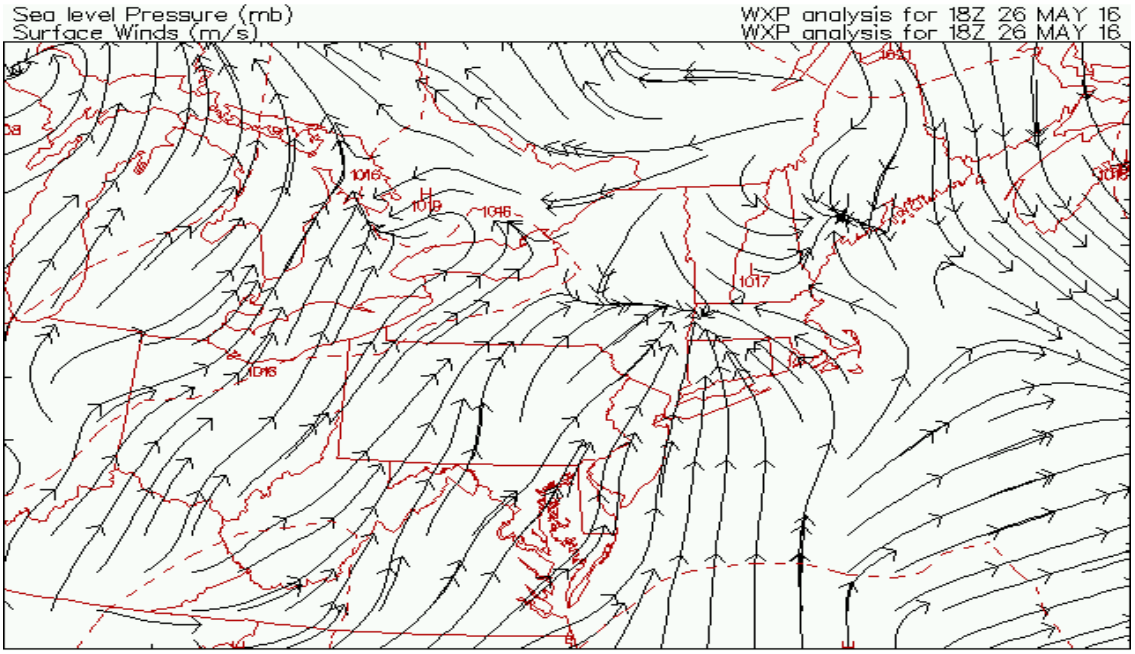


May 25, 2016 NWS Daily Surface Weather Analysis map (http://www.wpc.ncep.noaa.gov/dailywxmap/index.html) with surface wind and sea-level pressure analysis focused on northeast US (http://vortex.plymouth.edu/myo/sfc/ovrmap-a.html). Analysis indicates fair weather with general west to west-northwest flow into western MA.

Figure 11

Surface Analysis Showing Variable Winds into Western Massachusetts due to Surface Frontal System – May 26, 2016



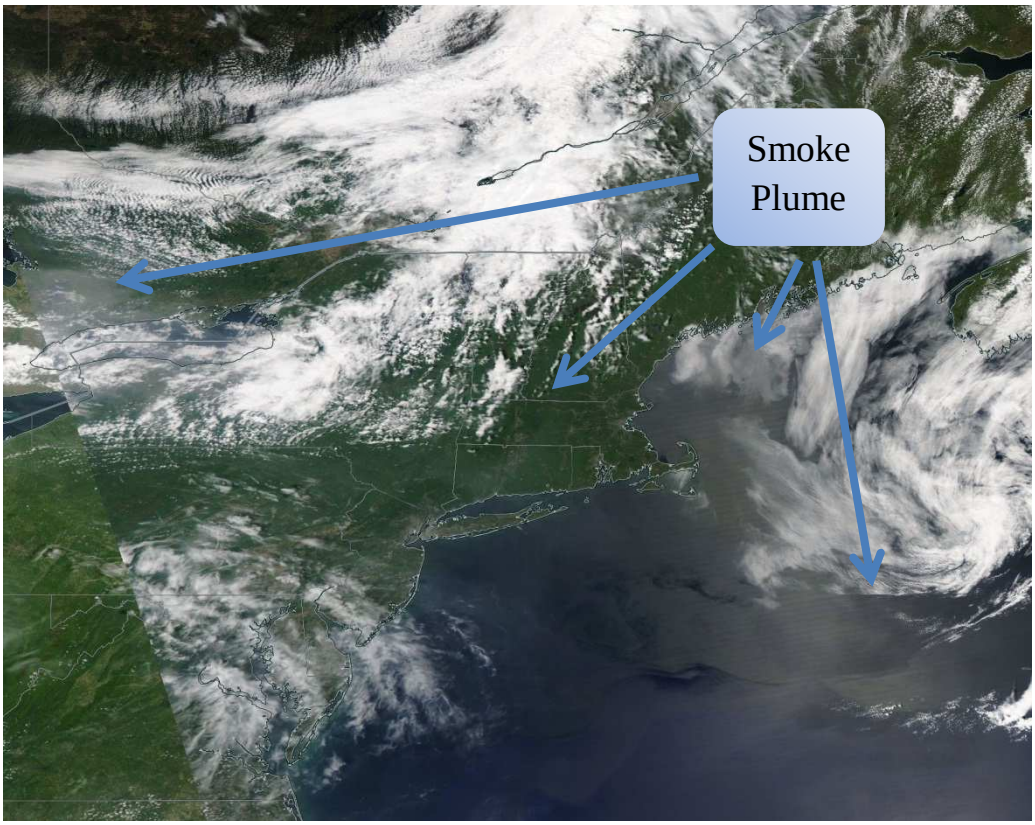


May 26, 2016 NWS Daily Surface Weather Analysis map (http://www.wpc.ncep.noaa.gov/dailywxmap/index.html) with surface wind and sea-level pressure analysis focused on northeast US (http://vortex.plymouth.edu/myo/sfc/ovrmap-a.html). Analysis indicates fair weather with variable surface winds in western MA due to position of cold front over the area.

Figures 12 and 13 present visible satellite imagery of the northeast U.S. from May 25 and 26 respectively. Each picture captures the smoke plume over Massachusetts and surrounding area. **Figure 14** shows the view from a webcam atop Talcott Mountain approximately 20 miles south - southwest of Springfield, Massachusetts looking toward Hartford, Connecticut. The photographs indicate a generally smoke free view on May 24. However, beginning on May 25 and continuing on May 26, the area is clearly affected by the smoke plume.

Figure 12

Visible Satellite Image Showing Smoke Over Massachusetts and Surrounding Area – May 25, 2016



May 25, 2016 visible satellite image of northeast US showing wildfire smoke plume now over the region (appearing as a lighter white and grayish brown as compared to clouds in brighter white. (https://worldview.earthdata.nasa.gov/)

Figure 13

Visible Satellite Image Showing Smoke Over Massachusetts and Surrounding Area – May 26, 2016

May 26, 2016 visible satellite image of northeast US showing wildfire smoke plume remaining over the region (appearing as a lighter white and grayish brown as compared to clouds in brighter white. (https://worldview.earthdata.nasa.gov/)

Figure 14

Webcam from Talcott Mountain Overlooking Hartford, CT Showing Smoke at Ground Level on May 24-26

Webcam Views from Nearby Talcott Mountain (20miles south southwest of Springfield, MA) Looking Toward Hartford, CT. Capture from May 24 indicates a relative smoke-free view. Capture from May 25 and 26 show wildfire plume affecting the region. Photos courtesy of Connecticut DEEP.

Figure 15 presents the HMS smoke data for May 25 and 26 along with the late afternoon/early evening observed ozone levels. The data show that on each day, ozone levels in the northeast, and in particular Massachusetts, were elevated in the presence of the wildfire plume.

Figure 15

Late Afternoon/Early Evening Ozone Concentrations with Wildfire Locations and Smoke Plumes – May 25-26, 2016

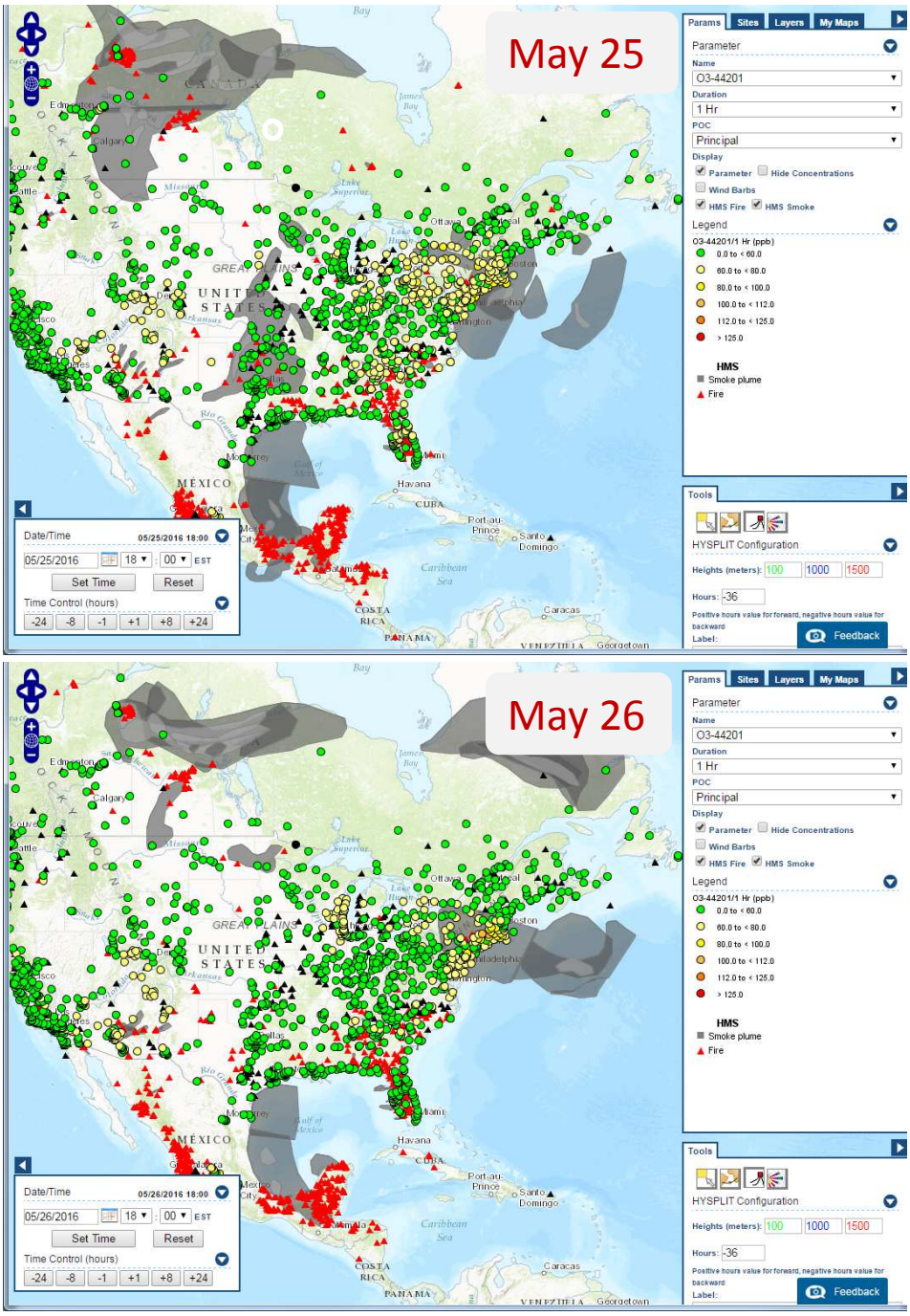


Figure showing location of fires and smoke (from HMS fire and smoke data) along with late afternoon ozone levels. Elevated ozone levels (yellow points) evident in the northeast including Massachusetts while simultaneously under the influence of the wildfire plume (denoted as darker gray area). Display generated via AirNow-Tech (http://www.airnowtech.org/)

Figure 16 presents CMAQ forecast model data that continued to under-predict ozone levels by a significant margin in the northeast including greater than 20 ppb in central and western areas of Massachusetts.

Figure 16

Model Predicts Low Ozone as Plume Spreads in Northeast – May 25-26

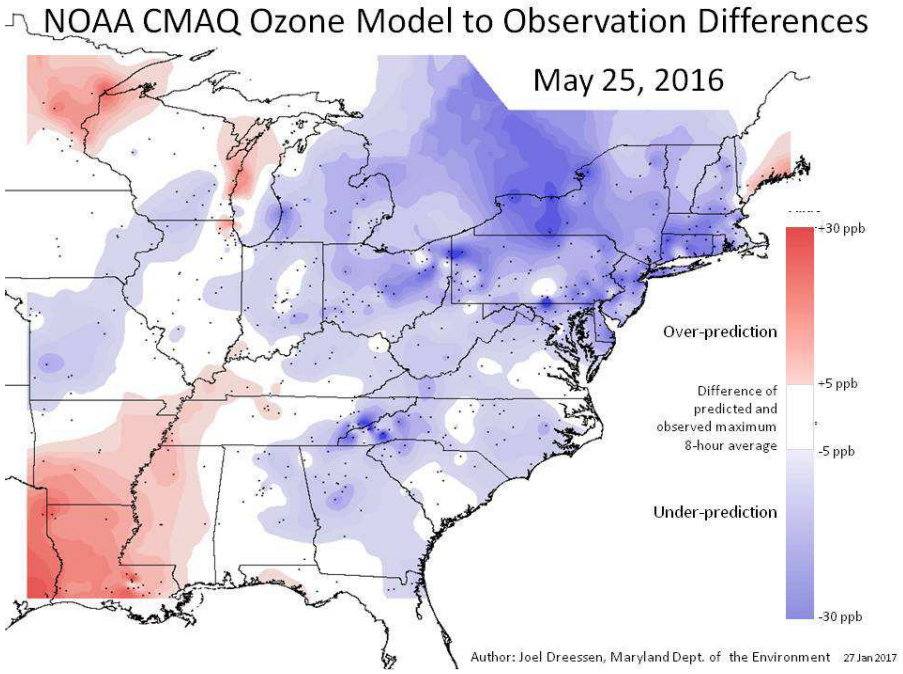


Figure showing CMAQ model bias to observed ozone levels. Blue shadings indicate degree of model under-prediction as smoke influences ozone levels across much of the northeast. Image courtesy of Joel Dreessen MDDEP.

Figure 16 (continued)

Model Predicts Low Ozone as Plume Spreads in Northeast – May 25-26

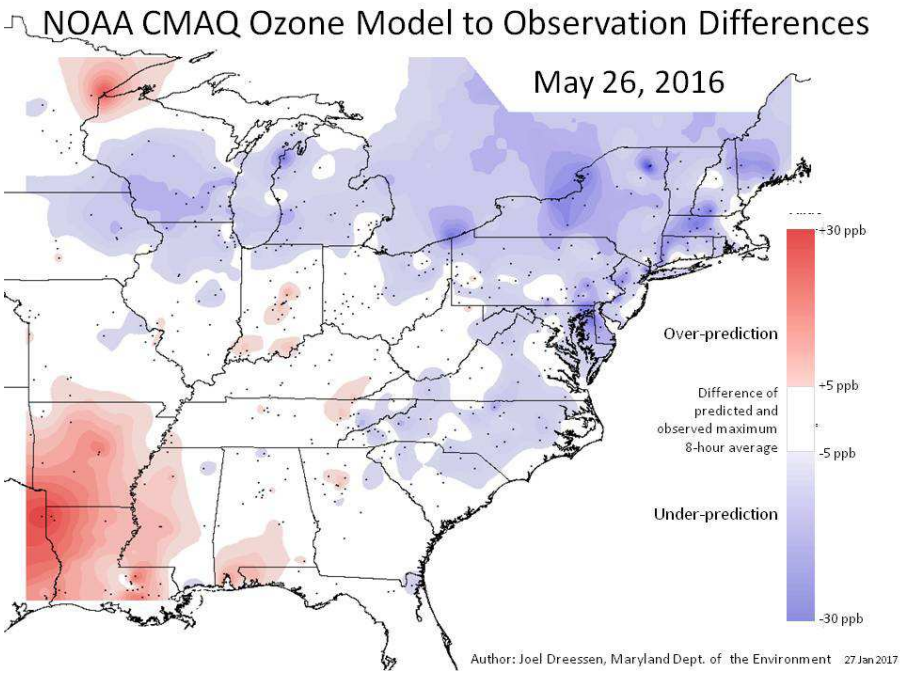
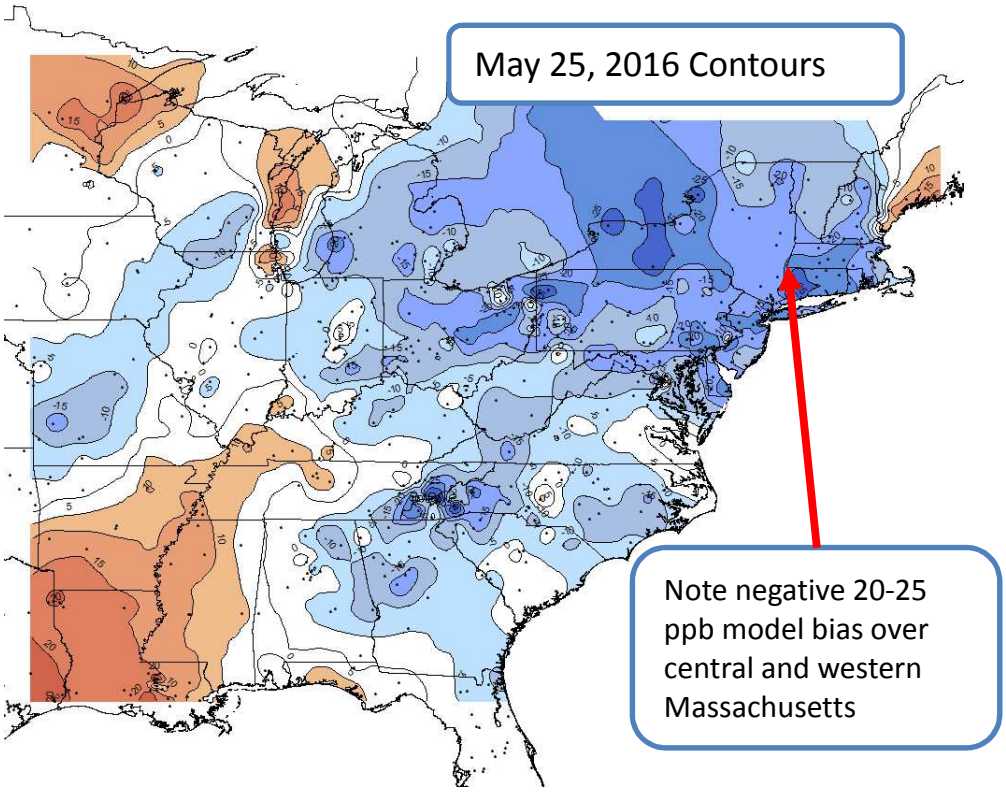


Figure showing CMAQ model bias to observed ozone levels. Blue shadings indicate degree of model under-prediction as smoke influences ozone levels across much of the northeast. Image courtesy of Joel Dreessen MDDEP.

Figure 16 (continued)

Model Predicts Low Ozone as Plume Spreads in Northeast – May 25-26



May 25 - Figure showing magnitude of CMAQ model bias to observed ozone levels. Blue shadings indicate degree of model under-prediction as smoke influences ozone levels across much of the northeast. Image courtesy of Joel Dreessen MDDEP. Model bias is >20 ppb in portions of Massachusetts likely due to non-inclusion of wildfire emissions in the model.

8. Demonstration of Wildfire Plume Affecting Ozone Levels at Chicopee and Ware Monitors

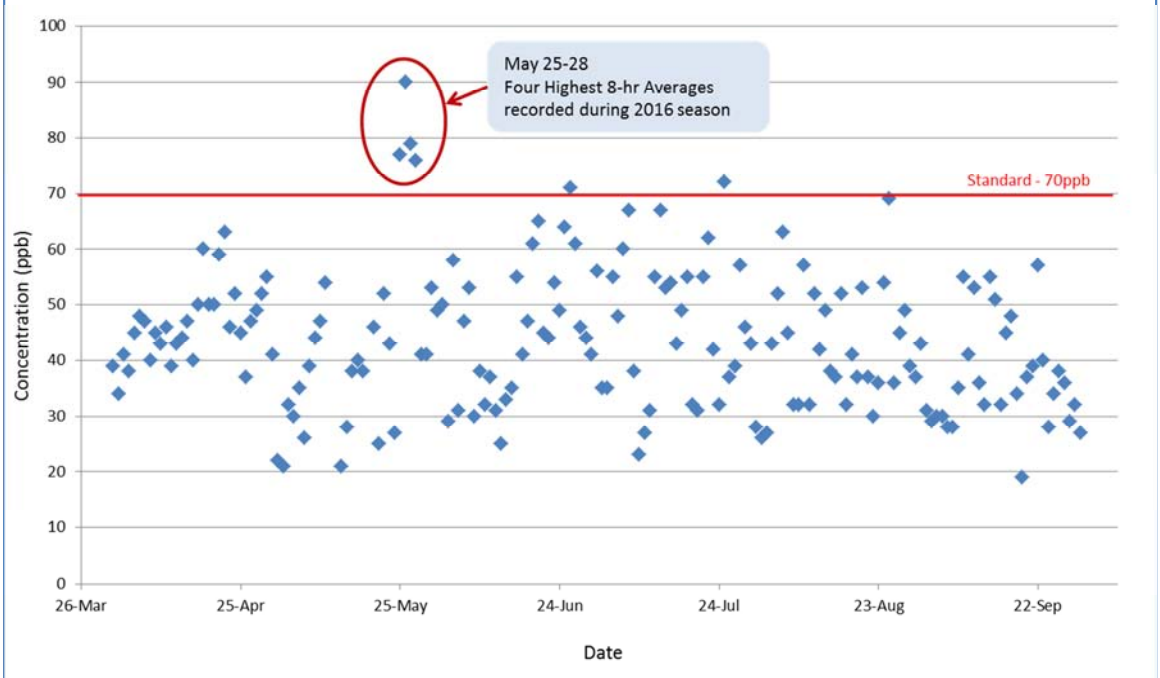
As previously described, areas of elevated ozone coinciding with smoke plumes from the Fort McMurray wildfire were transported from the upper Midwest and Great Lakes regions and began to affect northeastern areas, including Massachusetts, on May 25. Monitoring data from west-central Massachusetts on May 25 and 26 indicate that elevated ozone levels coincided with the appearance of the wildfire plume at those monitors. Data also indicate that levels may have been exacerbated during the following two days – May 27 and 28 – as meteorological conditions more typically favorable for ozone development likely combined with elevated ozone remaining from the prior two days.

Figures 17 and 18 present maximum 8-hour average ozone concentrations as recorded during the 2016 ozone season at Chicopee and Ware, respectively. For Chicopee, the plotted data clearly indicate that all four maximum 8-hour averages for the May 25 through May 28 period are the four highest recorded during the season. Similarly at Ware, three of the four maximum 8-hour averages (May 25-27) are the highest recorded during the 2016 season.

Figure 17

Chicopee 2016 –

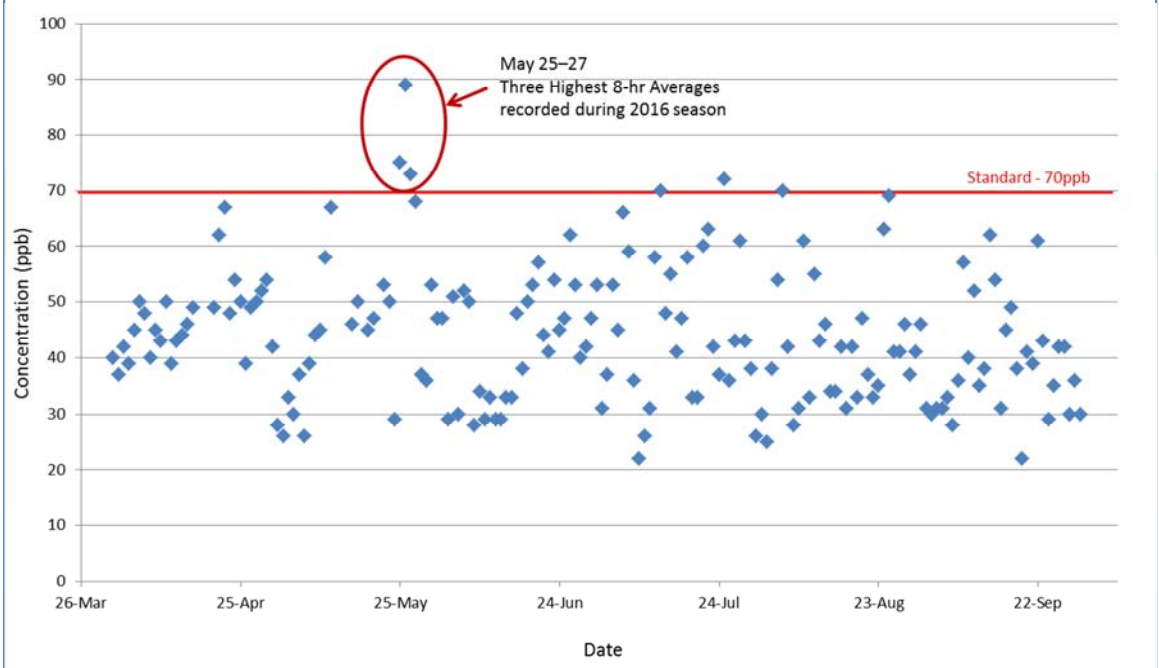
Daily Maximum 8-Hr Average Ozone Concentrations



Data plot showing daily maximum 8-hour average ozone concentrations as recorded at Chicopee during the 2016 season (April 1-September 30). Circled data points show that the plume-affected days registered the four highest values in the 2016 season.

Figure 18

Ware– 2016 – Daily Maximum 8-Hour Average Ozone Concentrations



Data plot showing daily maximum 8-hour average ozone concentrations as recorded at Ware monitoring location during the 2016 season (April 1-September 30). Circled data points show that the plume-affected days registered three of the four highest values in the 2016 season.

For a longer historical perspective, **Figures 19 and 20** present maximum 8-hour average ozone concentrations from Chicopee and Ware, respectively, as recorded during the early portion of the 2011-2016 ozone seasons (May 1-June 30). For Chicopee, the data show that all four recorded maximum 8-hour averages for the May 25 through May 28 episode are the four highest recorded for this early ozone season timeframe in the most recent six-year period. For Ware, the data show that the May 25 and May 26 maximum 8-hour averages are two of the four highest recorded during the May-June timeframe in the most recent six-year period.

Figure 19

Chicopee– Six-Year Early Season Ozone History

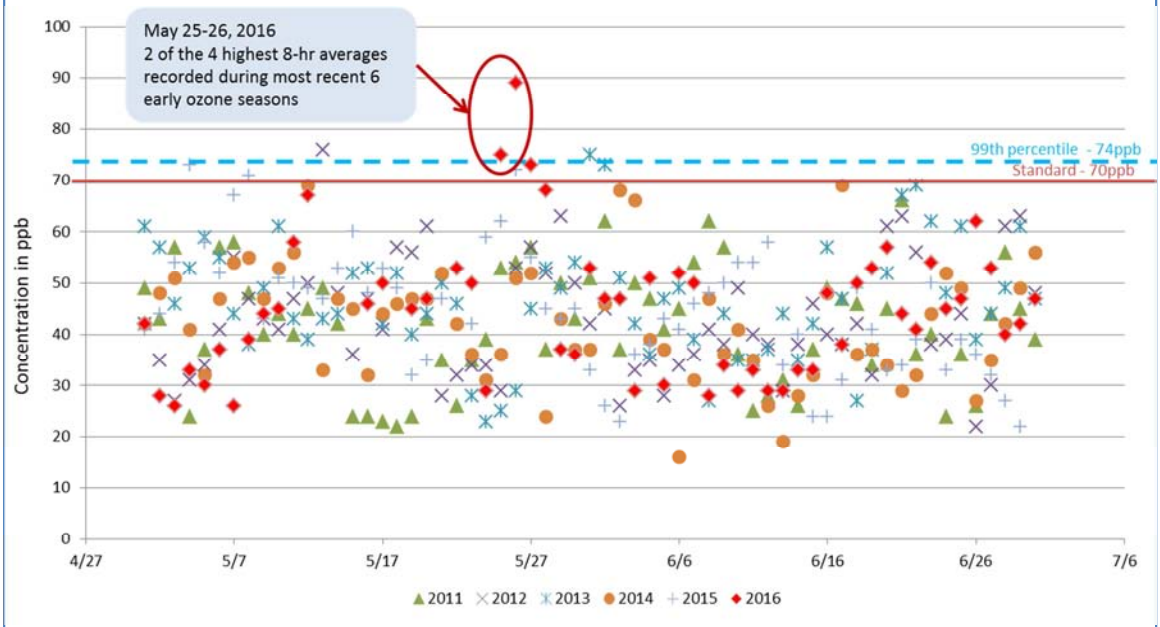
Daily Maximum 8-hour Average Ozone Concentration for
May 1-June 30, 2011-2016

Data plot showing daily maximum 8-hour average ozone concentrations as recorded at Chicopee during the most-recent six early ozone seasons (2011-2016 May 1 – June 30). Circled data points show that the plume-affected days registered the four highest values in this multi-year period.

Figure 20

Ware – Six-Year Early Season Ozone History

Daily Maximum 8-hour Average Ozone Concentration for
May 1-June 30, 2011-2016



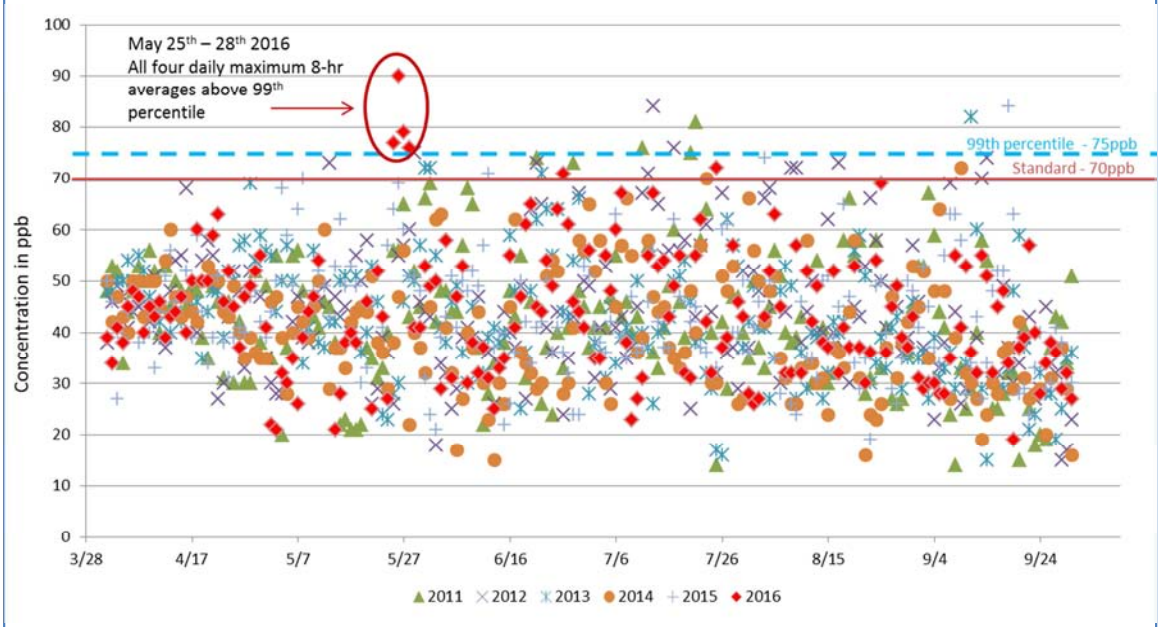
Data plot showing maximum daily 8-hour average ozone concentrations as recorded at Ware during the most-recent six early ozone seasons (2011-2016 May 1 – June 30). Circled data points show that the plume-affected days registered two of the four highest values in this multi-year period.

Figures 21 and 22 present maximum daily 8-hour average ozone concentrations from Chicopee and Ware, respectively, as recorded during the entire ozone season (April 1-September 30) for each of the last six years. For Chicopee, the data show that all four recorded maximum 8-hour averages for the May 25-28 episode are above the 99th percentile. For Ware, the data show that the May 25 and May 26 maximum 8-hour averages are also above the 99th percentile. Also notable are the 90 ppb and 89 ppb concentrations recorded at Chicopee and Ware, respectively, on May 26 as these are the highest recorded concentrations with a margin of 6 ppb and 5 ppb, respectively, over this extensive data record.

Figure 21

Chicopee 6-Year Ozone Season History

Daily Maximum 8-hr Average Ozone Concentration for Ozone Season
(April 1 - Sep 30) 2011-2016

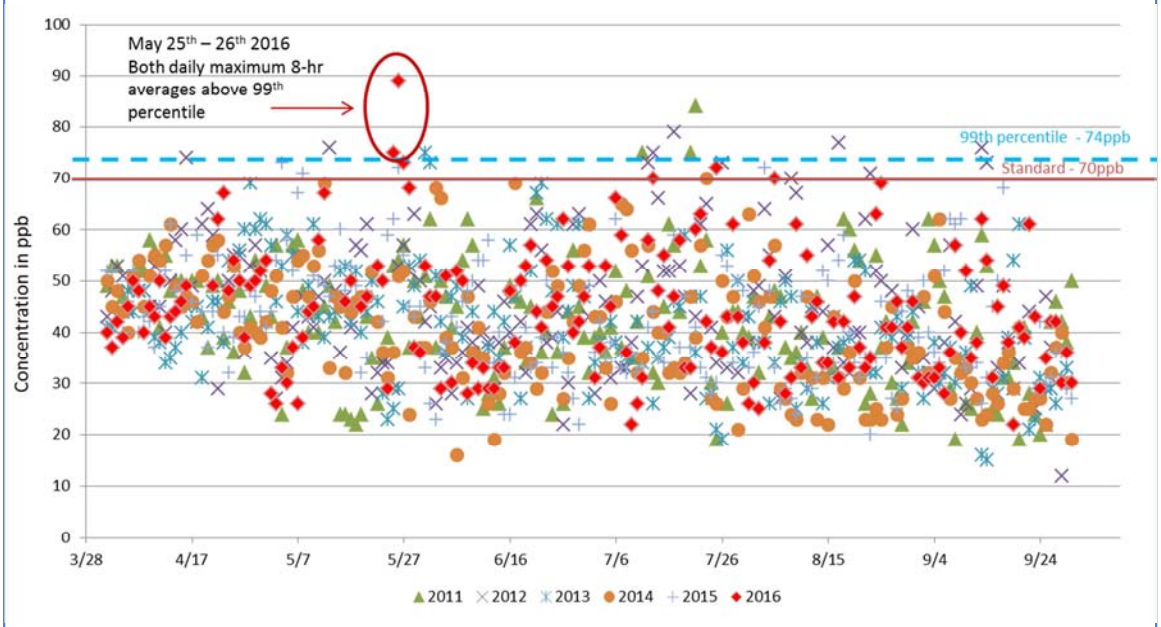


Data plot showing maximum daily 8-hr average ozone concentrations as recorded at Chicopee during the most-recent 6 ozone seasons (2011-2016 April 1 – September 30). Circled data points show that the plume-affected days had recorded concentrations above the 99th percentile in this multi-year period. Note that May 26th, 2016 concentration is the highest recorded during this 6-yr period with margin of 6 ppb.

Figure 22

Ware Six-Year Ozone Season History

Daily Maximum 8-hour Average Ozone Concentration for Ozone Season
(April 1 - Sep 30) 2011-2016



Data plot showing maximum daily 8-hour average ozone concentrations as recorded at Ware during the most-recent six ozone seasons (2011-2016 April 1 – September 30). Circled data points show that the plume-affected days had recorded concentrations above the 99th percentile in this multi-year period. Note that May 26, 2016 concentration is the highest recorded during this six-year period with margin of 5 ppb.

HMS smoke data superimposed on a map of the northeast U.S. is presented in **Figures 23 and 24** for May 25 and May 26, respectively, and indicates that the Chicopee and Ware locations were under the influence of the wildfire plume coinciding with these historically high ozone concentrations.

Figure 23

Hazard Mapping System (HMS) Satellite Smoke Data

May 25, 2016

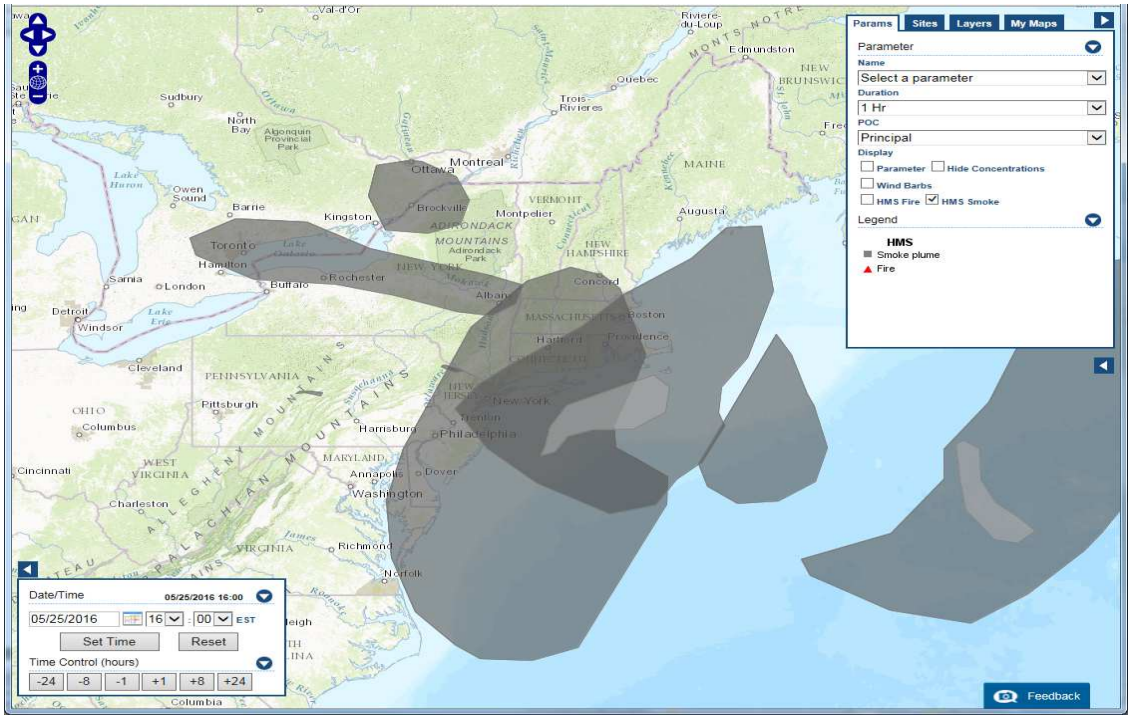


Figure showing location of smoke (from HMS fire and smoke data) over northeast US on May 25, 2016. Display generated via AirNow-Tech (http://www.airnowtech.org/)

Figure 24

Hazard Mapping System (HMS) Satellite Smoke Data

May 26, 2016

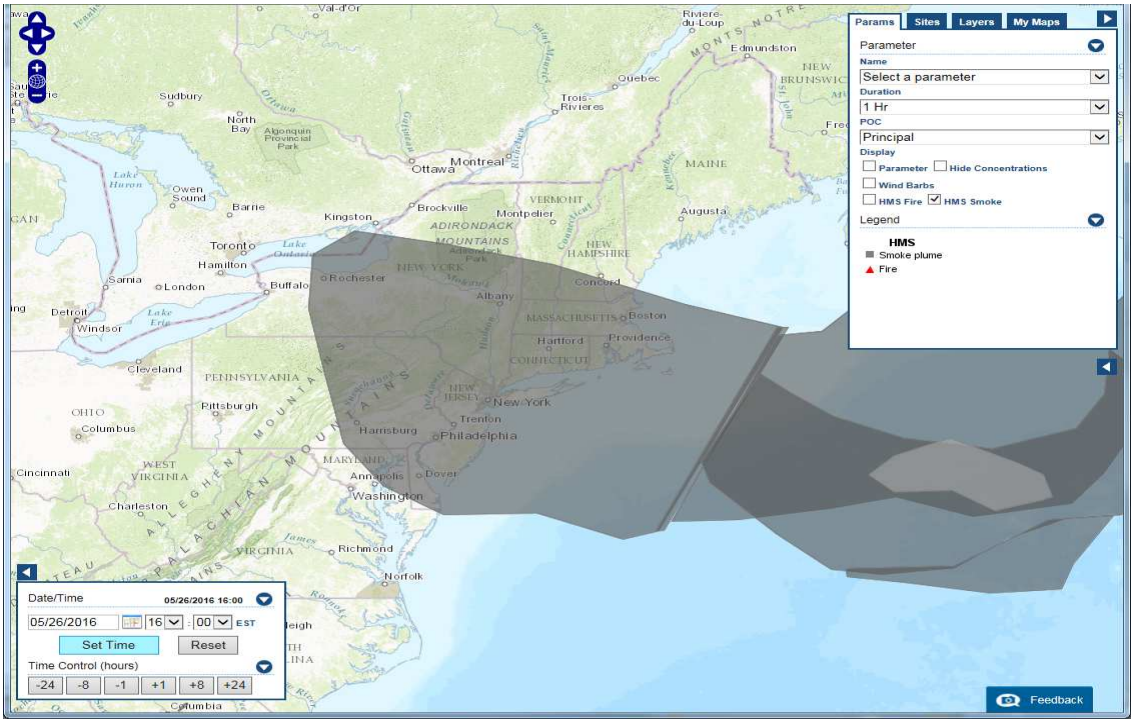


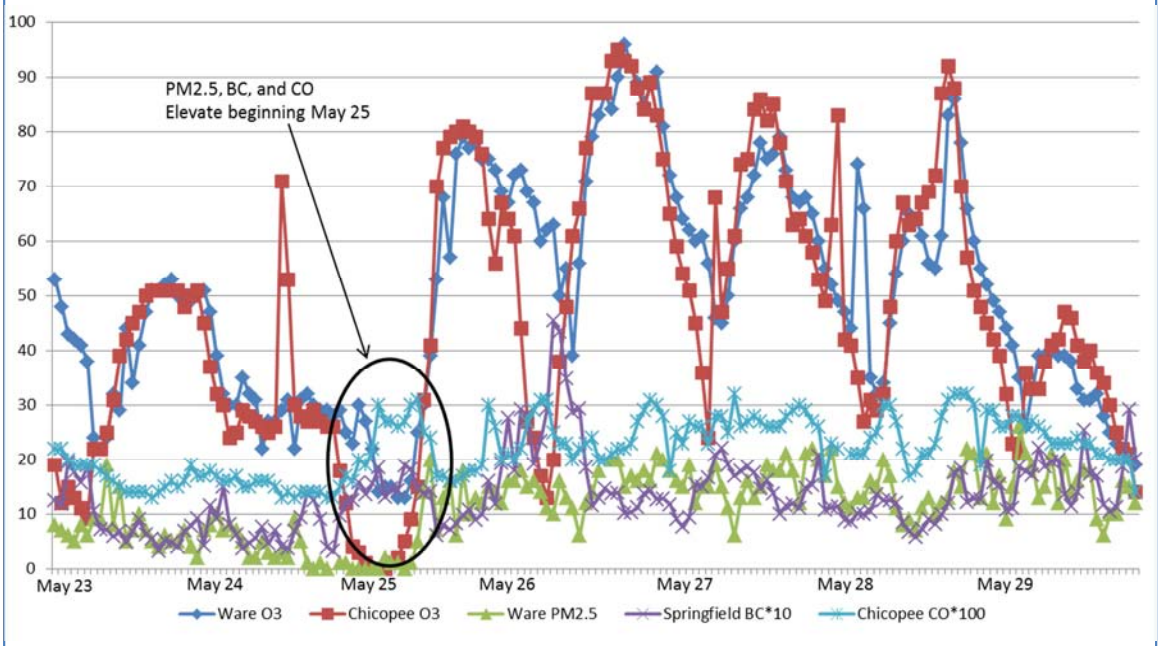
Figure showing location of smoke (from HMS fire and smoke data) over northeast US on May 26, 2016. Display generated via AirNow-Tech (http://www.airnowtech.org/)

Additional evidence of smoke affecting the area comes from examining patterns in other pollutants (PM2.5, CO, and black carbon) known to be associated with wildfire smoke plumes. MassDEP monitors for PM2.5 and CO are co-located at the Chicopee and Ware ozone monitors (respectively), and a black carbon monitor exists at the nearby Springfield monitoring station. **Figure 25** presents plotted hourly PM2.5, CO, and black carbon data with corresponding hourly ozone data for the May 23-29 period from the Chicopee and Ware monitoring sites. The hourly data show that levels of PM2.5, CO, and black carbon all increased on May 25. These relatively higher levels recorded at this time would correspond to the arrival of the smoke plume into the area.

Figure 25

Hourly Ozone, PM2.5, Black Carbon, and CO

Comparison of Hourly Chicopee and Ware Ozone Levels with PM2.5, Black Carbon (BC), and Carbon Monoxide (CO) Levels, May 23-29, 2016



Hourly PM2.5 (green line), black carbon (purple line), and CO (blue line) data recorded at area monitors indicate an increase in concentration levels beginning May 25.

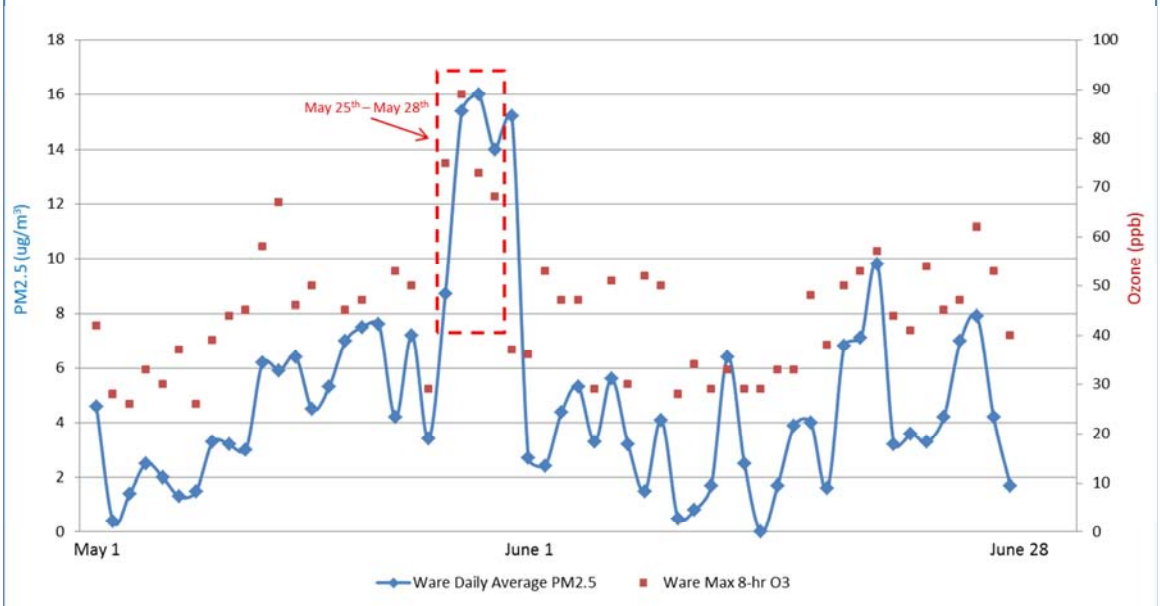
For a clearer picture, daily data for these same parameters was analyzed over the early ozone season (May 1-June 30). **Figure 26** presents maximum 8-hour average ozone concentrations from Ware for the May-June 2016 timeframe along with daily PM2.5 concentrations also collected at Ware. **Figure 27** presents maximum 8-hour average ozone concentrations from Chicopee along with daily average CO data also collected at Chicopee**. Figure 28** presents the Ware ozone data along with daily average black carbon data collected at the nearby Springfield monitor.

All of these plots clearly depict trends with a distinct increase and decrease in PM2.5, CO, and black carbon concentrations that coincide with the May 25 through May 28 elevated ozone episode. This pattern provides further evidence that the Chicopee and Ware monitors were affected by the wildfire smoke plumes on these days.

Figure 26

Comparison Trends – PM2.5 and Ozone

Ware – May-June 2016

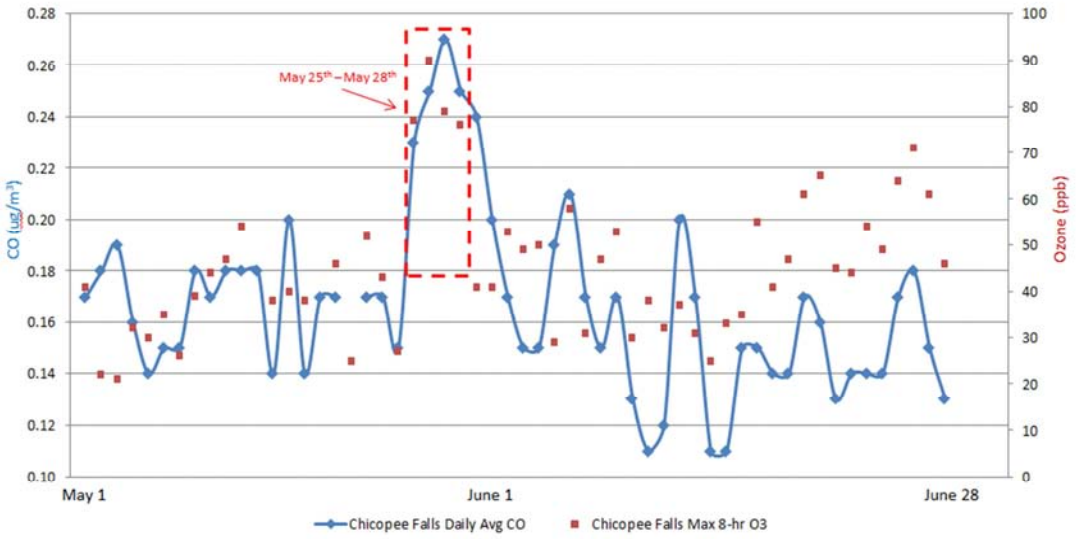


Data plot showing daily average PM2.5 concentrations with trend (blue points and line) with corresponding daily maximum 8-hour average ozone concentrations as recorded at Ware (red points without line). A distinct rise and fall in PM2.5 levels likely associated with the wildfire smoke is evident during the late May

Figure 27

Comparison Trends – CO and Ozone

Chicopee – May-June 2016

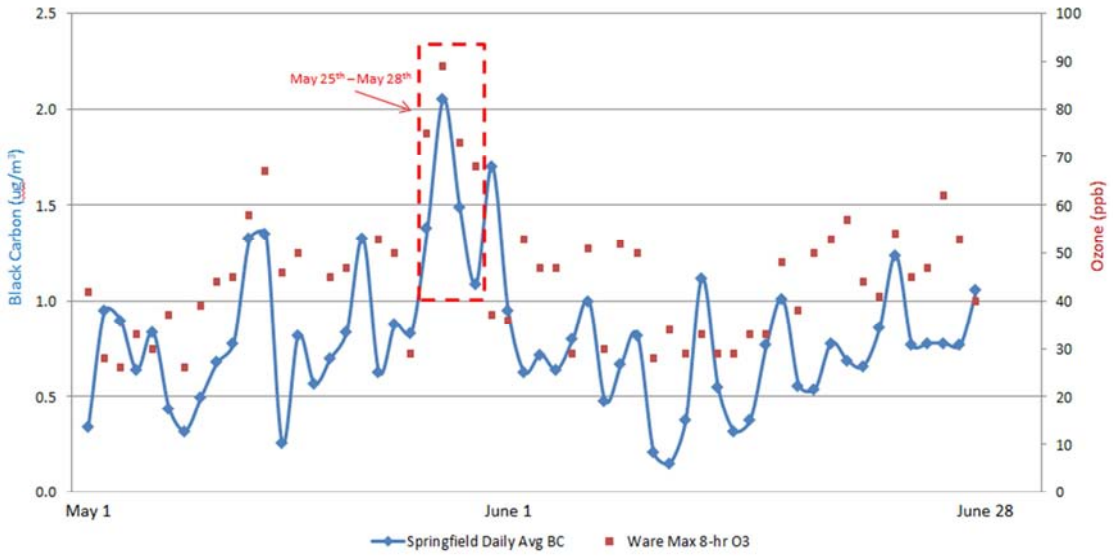


Data plot showing daily CO concentrations with trend (blue points and line) with corresponding daily maximum 8-hour average ozone concentrations as recorded at Chicopee (red points without line). A distinct rise and fall in CO levels likely associated with the wildfire smoke is evident during the late May episode.

Figure 28

Comparison Trends – Black Carbon and Ozone

Ware and Springfield – May-June 2016



Data plot showing daily black carbon concentrations with trend (blue points and line) as recorded at Springfield, MA with corresponding daily maximum 8-hour average ozone concentrations recorded at Chicopee (red points without line). A distinct rise and fall in black carbon levels likely associated with the wildfire smoke is evident during the late May episode.

For an additional analysis of parameters that are typically associated with wildfire smoke plumes, data from Springfield and the nearby Mohawk Mountain monitoring location in Cornwall, Connecticut was examined. The Mohawk Mountain location resides approximately 40 miles southwest of the Springfield monitor at an elevation of 1683 feet above mean sea level. The rural elevated environment atop Mohawk Mountain provides a data collection point that could represent a regional scale with little obstruction to air transport from distant areas.

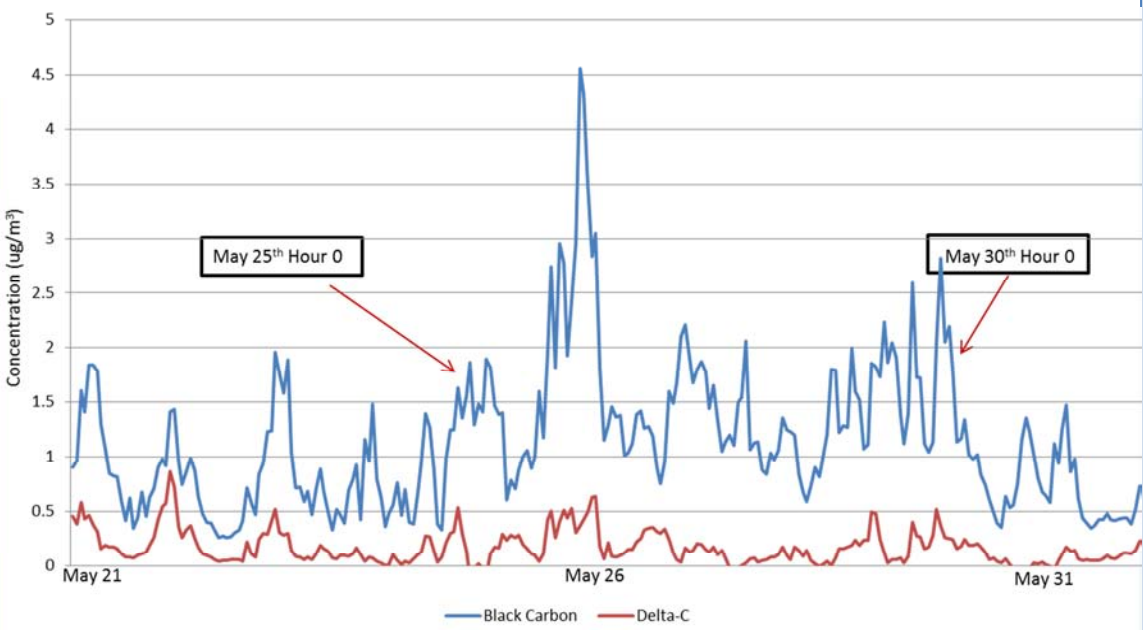
Figures 29 and 30 present hourly Black Carbon data as recorded at Springfield and Mohawk Mountain, respectively, for the period May 21-31. The data from both sites show a general increase of black carbon concentration beginning on May 25 coinciding with the arrival of the smoke plume to the area. Also presented in the figures is delta-C for the same period. This parameter is derived from carbon measurements taken with a 2-wavelength Aethalometer (370nm or UV-C minus 880nm or BC) at each site. Delta-C has been found to be a strong signal of wood smoke and can be another indicator of a wildfire as the source of a plume[12]. The delta-C data from Springfield does not indicate a strong signal during the period. In this case, the absence of the delta-C signal may be due to the lower elevation of the site (<90 feet above

[12] A Real-Time Wood Smoke Method – George Allen, NESCAUM 2006 (https://www3.epa.gov/ttnamti1/files/2006conference/allenrealtime.pdf

mean sea level). However, the delta-C data from the elevated site at Mohawk Mountain show a corresponding increase in concentration with the black carbon data, strongly indicating a wood smoke component within the plume. This pattern of increased black carbon concentrations from both sites and a corresponding increase in delta-C concentration recorded at the nearby elevated site is additional evidence that the wildfire plume was affecting the southern New England region including the Chicopee and Ware areas at the time of the elevated ozone episode.

Figure 29

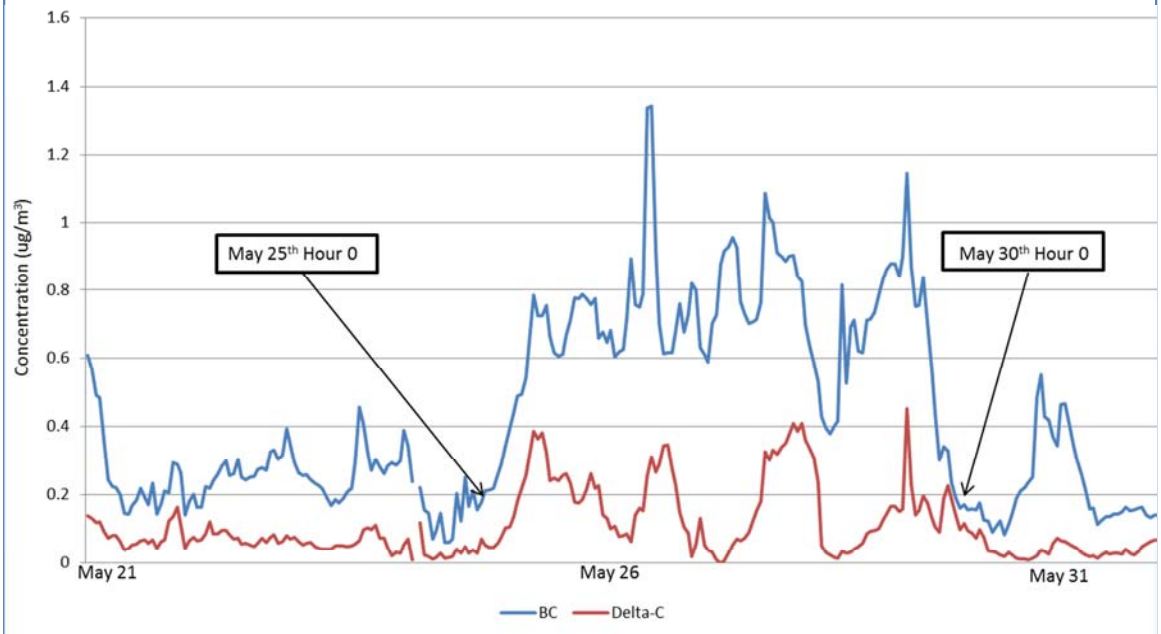
Springfield Hourly Black Carbon and Delta-C –
May 21-31, 2016



Springfield, MA Hourly Black Carbon and Delta-C May 21-31, 2016. Trend data indicates an increase in concentration level of black carbon beginning early on May 25 coinciding with arrival of smoke plume in the area. (Data courtesy of George Allen, NESCAUM)

Figure 30

Mohawk Mountain Hourly Black Carbon and Delta-C – May 21-31, 2016



Mohawk Mountain Cornwall, CT (Elev. 1683 feet) Hourly Black Carbon and Delta-C
May 21-31, 2016. Trend data indicates an increase in concentration level of both parameters beginning early on May 25 coinciding with arrival of smoke plume in the area. (Data courtesy of Connecticut DEEP)

9. Trajectory Analysis for the Episode

Elevated ozone in Massachusetts is typically the result of high temperatures combined with a southwest flow transporting high levels of precursors and ozone from the urban corridor of the northeast U.S. into the State. Airflow from the west, north and east is not typically associated with high levels of ozone, even with high summertime temperature levels.

To determine where the air in western Massachusetts was originating from the high ozone episode beginning May 25, back trajectories were generated using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model. This model calculates the position of parcels of air over time based on meteorological data. Different levels of transport can be specified for simultaneous analysis and display. This allows for better determination of a consistent flow in ascending levels of the atmosphere or if the flow changes direction/and or speed with height. Increments of six hours in each trajectory are indicated by a point on the trajectory line (longer spaces between points imply faster wind speeds). For this episode, 36-hour back-trajectories at the 100m, 1000m, and 1500m levels were generated to show where air parcels on the affected days originated.

Figures 31 and 32 depict 36-hour back trajectories for May 25 and 26, respectively, for the Chicopee and Ware monitoring locations. Also shown are ozone concentrations during the late afternoon (4:00pm EST) as well as HMS satellite smoke data. Both figures indicate that Massachusetts (and the region) was affected by smoke plumes from the wildfire during those two days and was at the same time experiencing elevated ozone. HYSPLIT back trajectory data show that air parcels were transported from the Great Lakes region across central and southern New York State to the Chicopee and Ware monitors.

Figure 31

HYSPLIT 36-Hour Back Trajectories for Chicopee and Ware – May 25, 2016

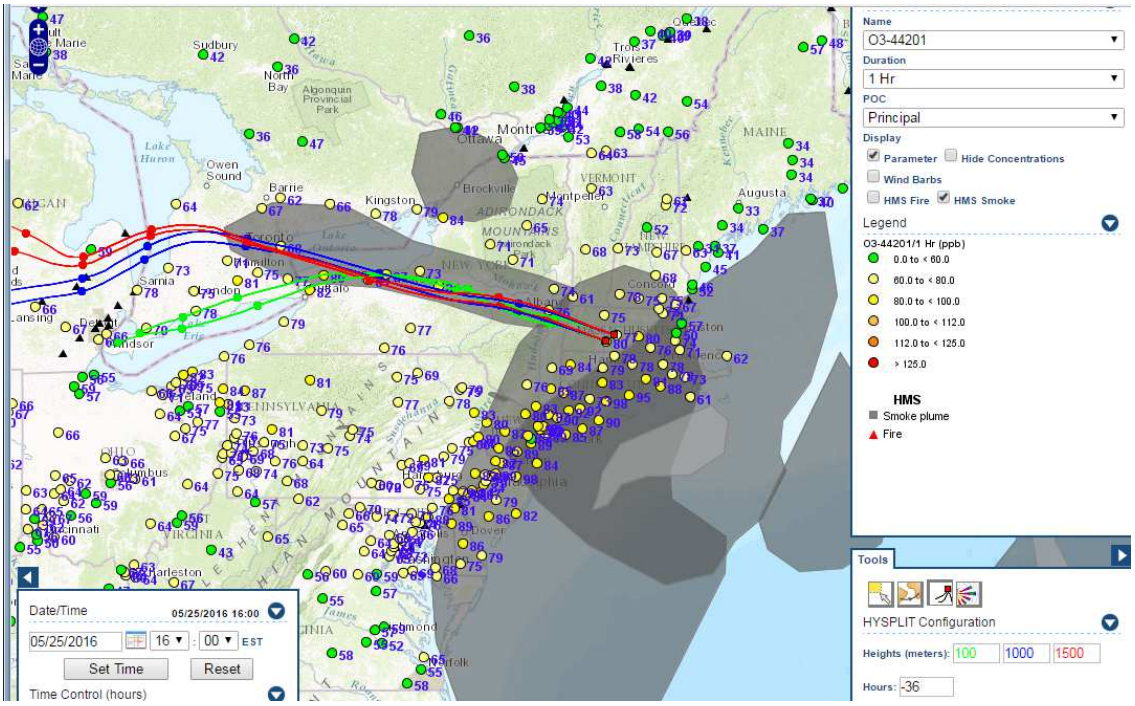


Figure showing location of smoke (from HMS fire and smoke data) along with late afternoon ozone levels in the northeast US on May 25. 36-hour back trajectories calculated with HYSPLIT model also overlaid on map showing air transport from normally "clean" source areas to the west-northwest of Chicopee and Ware monitoring locations and at all three levels analyzed (100m, 1000m and 1500m). Display generated via AirNow-Tech (http://www.airnowtech.org/)

Figure 32

HYSPLIT 36-Hour Back Trajectories for Chicopee and Ware – May 26, 2016

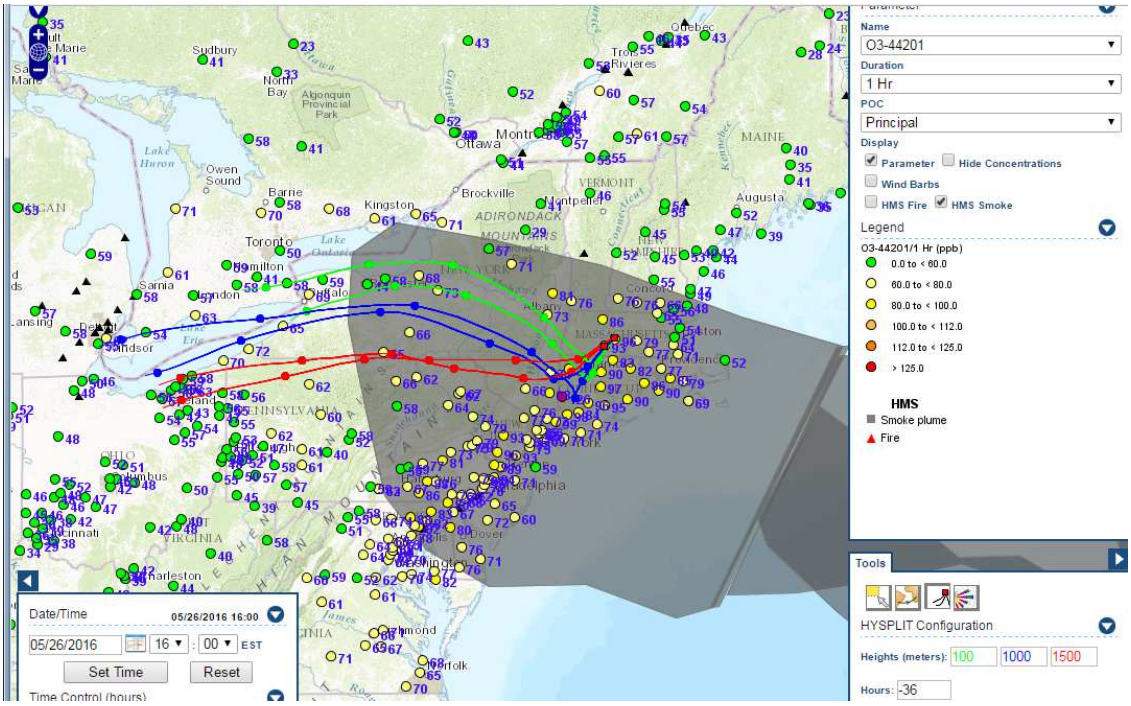


Figure showing location of smoke (from HMS fire and smoke data) along with late afternoon ozone levels in the northeast US on May 26. 36-hour back trajectories calculated with HYSPLIT model also overlaid on map showing air transport from normally "clean" source areas to the west and west-northwest of Chicopee and Ware monitoring locations and at all three levels analyzed (100m, 1000m and 1500m). Display generated via AirNow-Tech (http://www.airnowtech.org/)

The trajectories show air transport from a normally clean source region to the monitoring sites. Ozone levels are typically not elevated in western Massachusetts with this trajectory scenario and so the high ozone observed at this time is not explained by the typical upwind source emissions. Instead, the HMS satellite shows the presence of the Fort McMurray smoke plume, leading to the conclusion that both the Chicopee and Ware monitors were being influenced by the wildfire plume during this episode.

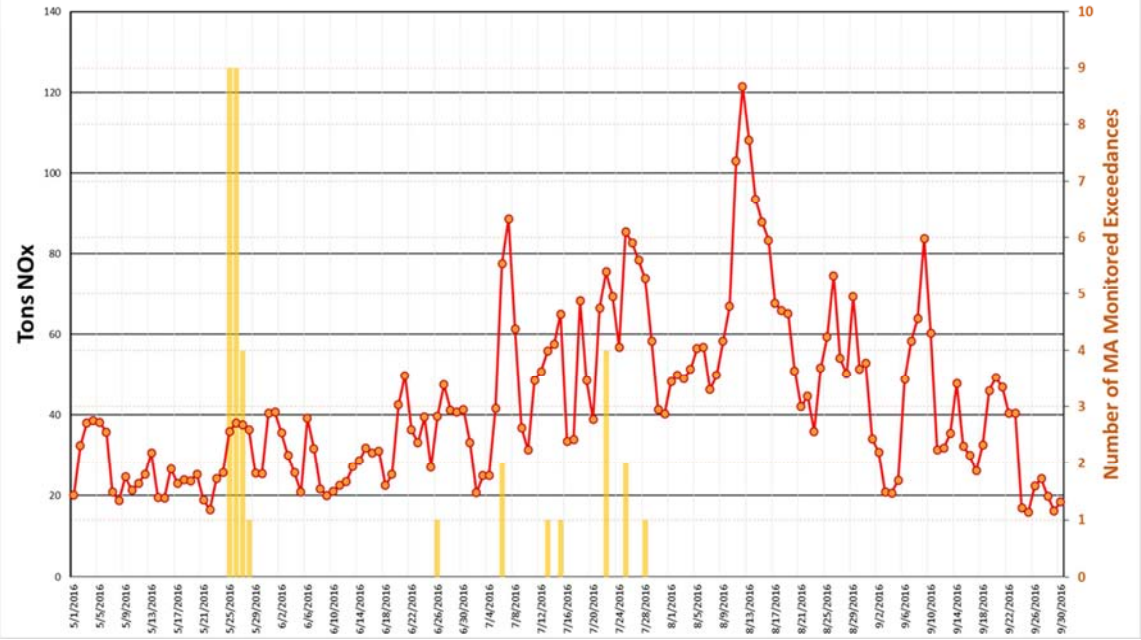
As additional evidence that air transport from New York State did not bring with it an unusually high level of emissions from sources within the State, data from EPA's Air Markets Program[13] was acquired and summarized in **Figure 33**. The data show that for 2016, NOx emissions from New York State were relatively low during the May 25-26 timeframe as compared to

[13] USEPA Air Markets Program Data (https://ampd.epa.gov/ampd)

summertime levels (July-August), while the number of monitored exceedances in Massachusetts was remarkably high.

Figure 33

New York Daily NOx Emissions and Massachusetts Ozone Exceedances – May-September, 2016



Trend line for NOx emissions indicates relatively low emissions during May and increasing in June-August. An unusual number of monitoring locations in Massachusetts exceeding ozone standard on May 25-26 occurred on days where air parcels were transported from New York State. The data supports the assumption that it is unlikely New York State NOx emissions contributed to unusually high levels of ozone in Massachusetts on these days.

Ozone and trajectory data are shown in **Figures 34 and 35** for May 27 and 28, respectively. Although similar elevated ozone levels are indicated on each figure across much of Massachusetts on these two days, trajectories indicate transport of air to the monitors from areas more to the south and southwest relative to May 25 and 26.

The trajectories from May 27 and 28 are more typical of a summertime airflow that would transport higher amounts of precursors and ozone from the northeast urban corridor into Massachusetts, resulting in relatively high ozone levels. However, because of the buildup of high ozone in the area during the previous two days and the presence of near ground-level

smoke as recorded at area monitors, ozone levels were likely exacerbated compared to a scenario without the buildup and smoke.

Figure 34

HYSPLIT 36-Hour Back Trajectories for Chicopee and Ware – May 27, 2016

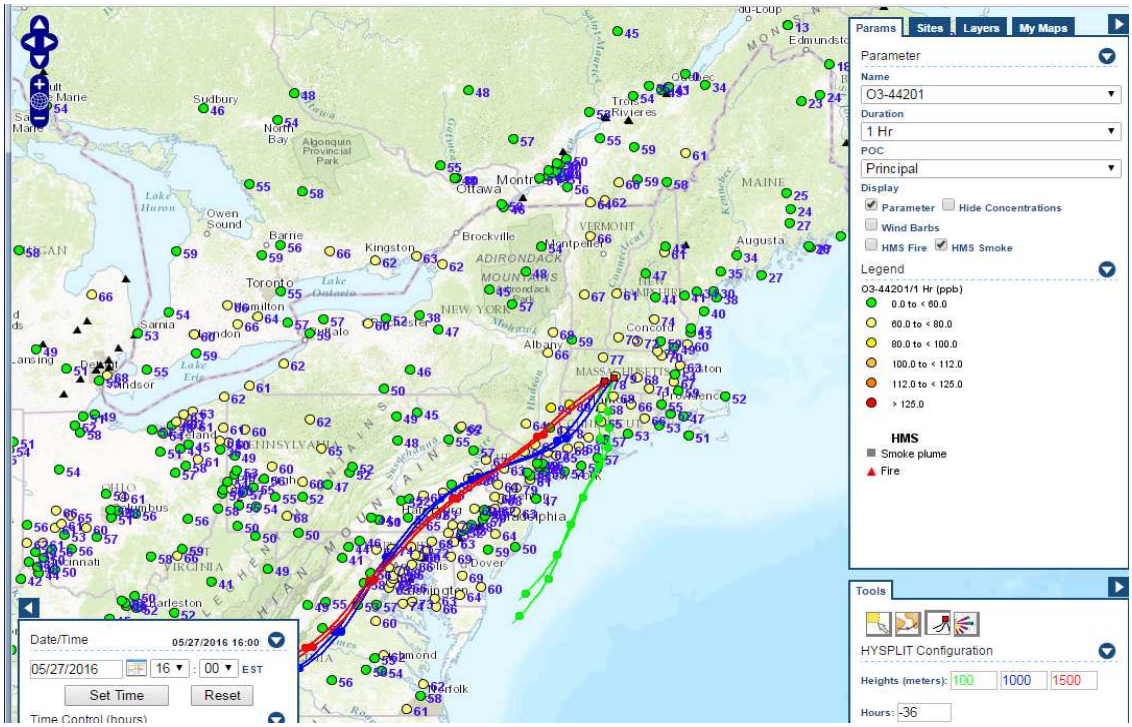


Figure showing late afternoon ozone levels in the northeast US on May 27. 36-hour back trajectories calculated with HYSPLIT model also overlaid on map showing air transport from the southwest to the Chicopee and Ware monitoring locations. Display generated via AirNow-Tech (http://www.airnowtech.org/)

Figure 35

HYSPLIT 36-Hour Back Trajectories for Chicopee and Ware – May 28, 2016

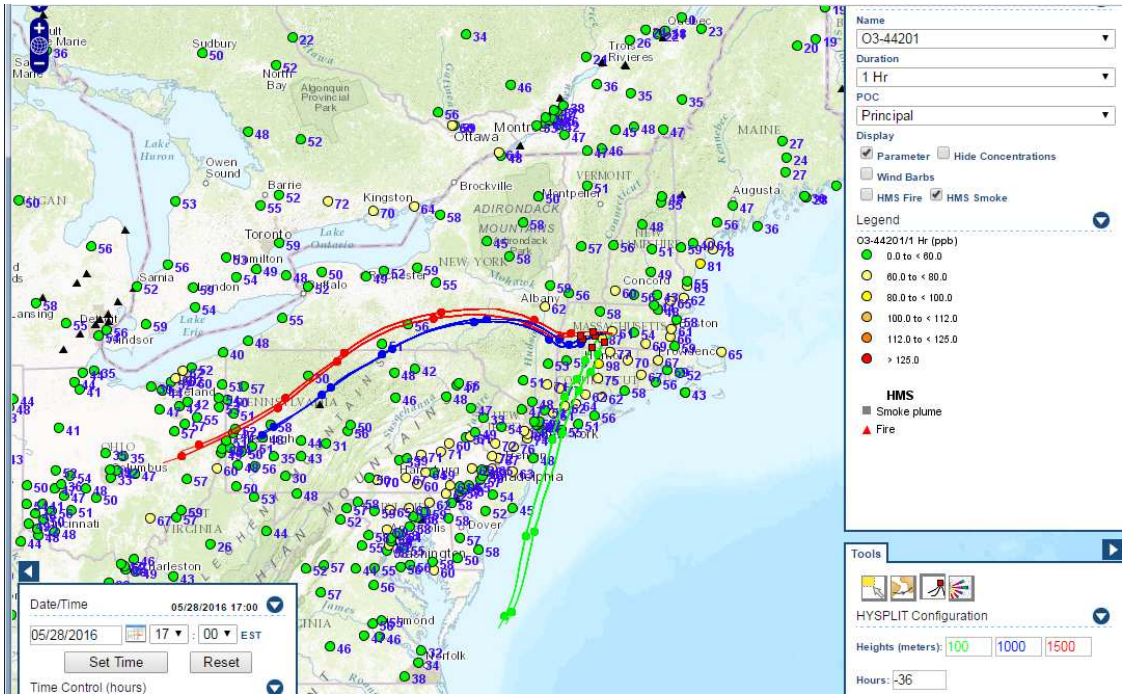


Figure showing late afternoon ozone levels in the northeast US on May 28. 36-hour back trajectories calculated with HYSPLIT model also overlaid on map showing air transport from the south and southwest to the Chicopee and Ware monitoring locations. Display generated via AirNow-Tech (http://www.airnowtech.org/)

10. Event Versus Non-Event Comparison

Recent Chicopee and Ware ozone data were analyzed and a number of days were identified with relatively high ozone. A set of 36-hour back trajectories were then generated for these days**. Figures 36, 37, and 38** present trajectory data for July 11, 2011; May 13, 2012; and July 13, 2012; respectively. Each of these days had maximum 8-hour average ozone concentrations above 70 ppb at both sites (maximum 8-hour average concentration is indicated on each figure). All of the figures show a general transport of air to the monitors from areas to the south and southwest. **Figure 39** presents a more recent example on July 25, 2016. This was the day both Chicopee and Ware recorded the next highest 8-hour average ozone concentration (72ppb) for the 2016 season (after the May 25-28 episode). Again, the trajectory data reveal a transport of air into western Massachusetts from areas to the south and southwest.

Figure 36

Example of High Ozone Day at Chicopee and Ware with HYSPLIT 36-Hour Back Trajectories – July 11, 2011

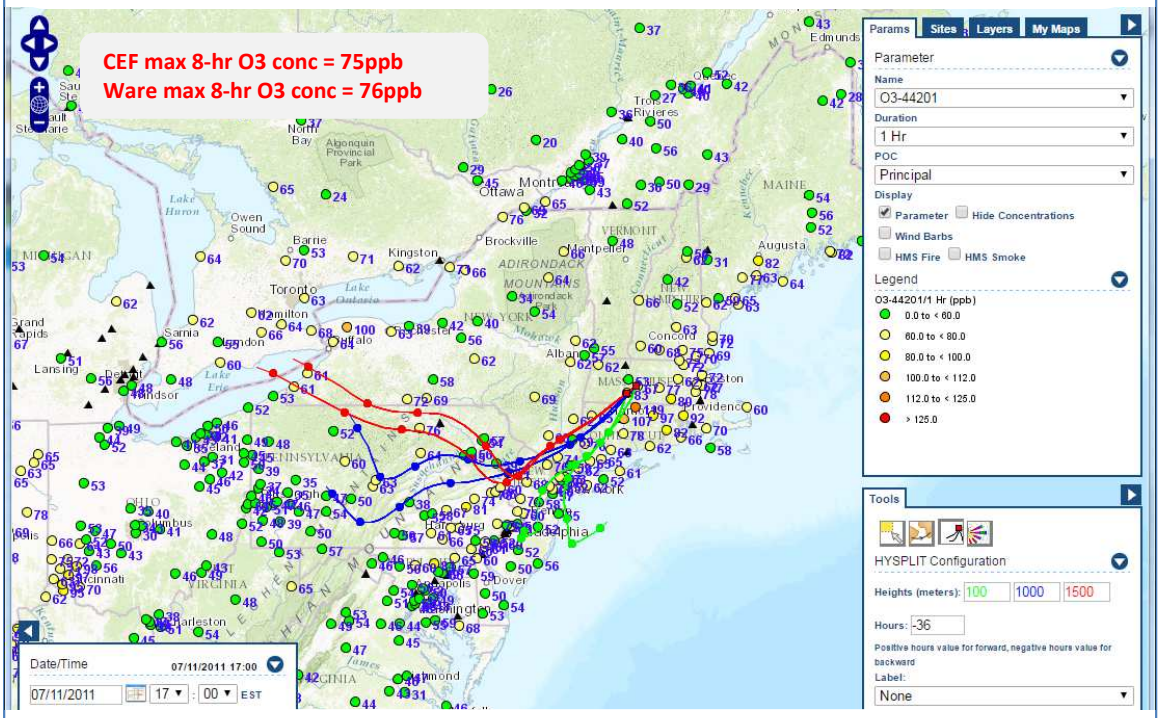


Figure showing late afternoon ozone levels in the northeast US on July 11, 2011. 36-hour back trajectories calculated with HYSPLIT model also overlaid on map showing air transport from the south and southwest to the Chicopee and Ware monitoring locations. Display generated via AirNow-Tech (http://www.airnowtech.org/)

Figure 37

Example of High Ozone Day at Chicopee and Ware with HYSPLIT 36-Hour Back Trajectories – May 13, 2012

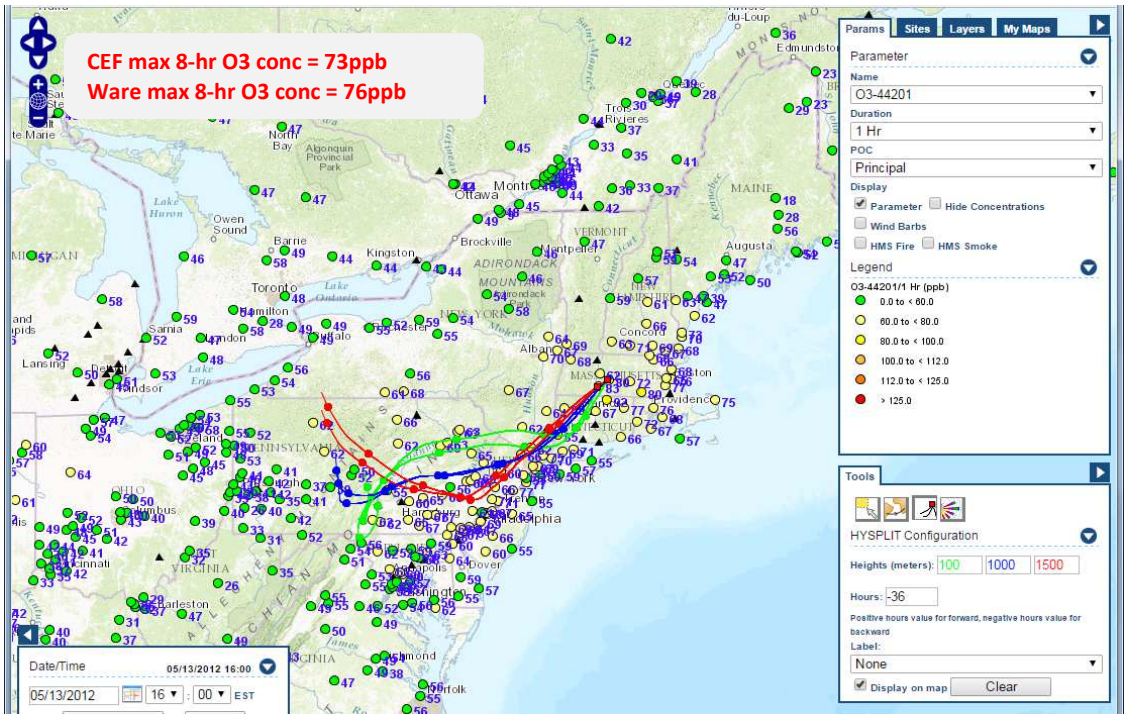


Figure showing late afternoon ozone levels in the northeast US on May 13, 2012. 36-hour back trajectories calculated with HYSPLIT model also overlaid on map showing air transport from the south and southwest to the Chicopee and Ware monitoring locations. Display generated via AirNow-Tech (http://www.airnowtech.org/)

Figure 38

Example of High Ozone Day at Chicopee and Ware with HYSPLIT 36-Hour Back Trajectories – July 13, 2012

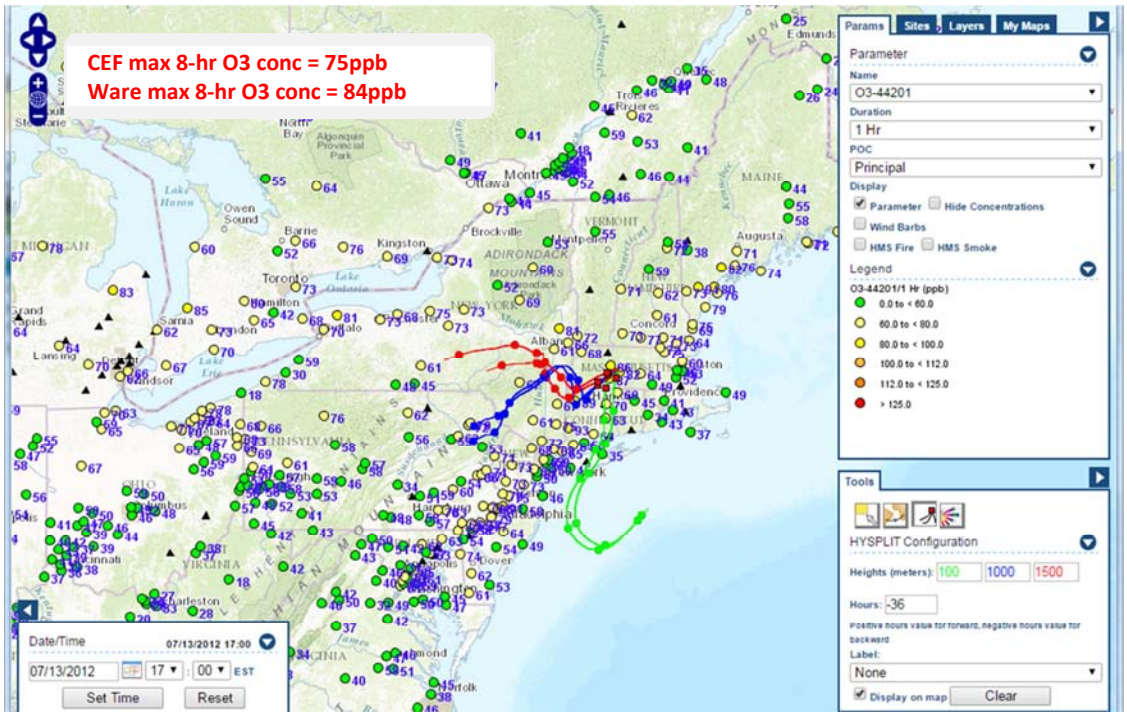


Figure showing late afternoon ozone levels in the northeast US on July 13, 2012. 36-hour back trajectories calculated with HYSPLIT model also overlaid on map showing air transport from the south and southwest to the Chicopee and Ware monitoring locations. Display generated via AirNow-Tech (http://www.airnowtech.org/)

Figure 39

Next Highest Max 8-Hour Ozone in 2016 at Chicopee and Ware with HYSPLIT 36-Hour Back Trajectories – July 25, 2016

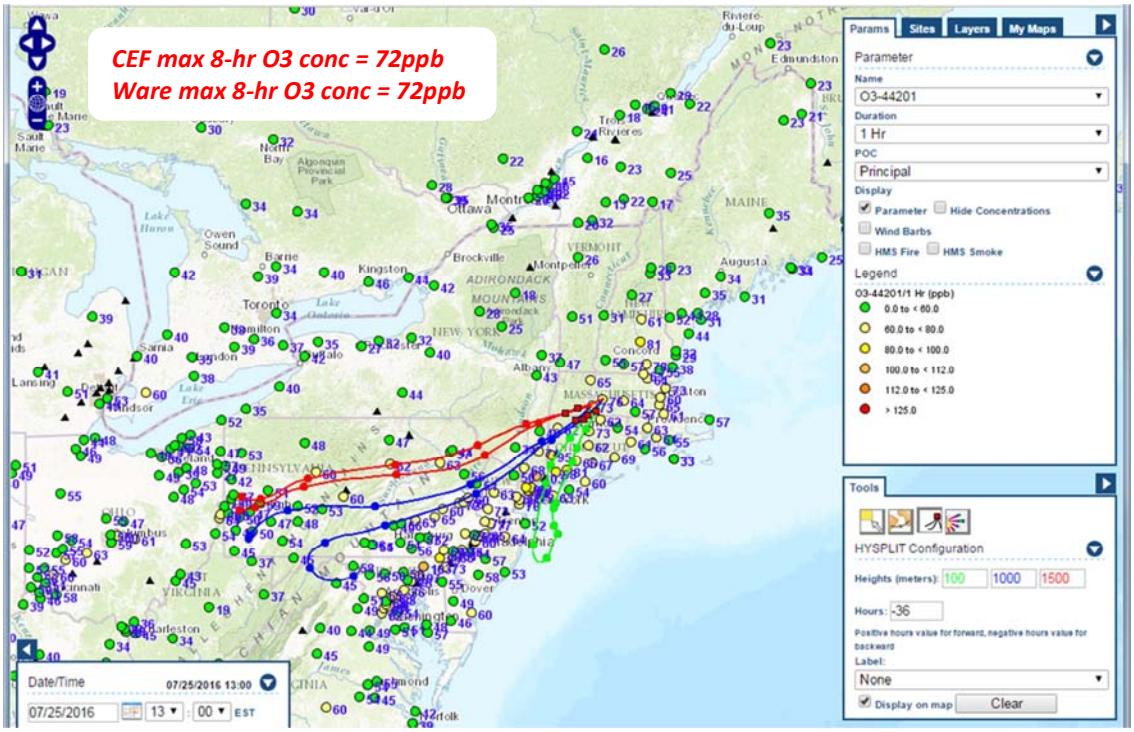


Figure showing late afternoon ozone levels in the northeast US on July 25, 2016. 36-hour back trajectories calculated with HYSPLIT model also overlaid on map showing air transport from the south and southwest to the Chicopee and Ware monitoring locations. Display generated via AirNow-Tech (http://www.airnowtech.org/)

11. Matching Day Analysis

A number of days from the 2016 ozone season were also identified as having 36-hour back trajectories similar to those of May 25-26 (i.e., the air was being transported from the Great Lakes /central New York State area). These days were then filtered to include only those averaging mostly sunny to sunny skies (as recorded at the airport in Chicopee) and with a maximum recorded temperature ranked in the top 10 for the season. **Figures 40, 41, 42, and 43** present the results. In all cases, maximum 8-hour average ozone concentrations remained relatively low (maximum 8-hour average indicated on each figure) despite mostly sunny skies and maximum temperatures ranging from 91 to 98 degrees F. These examples illustrate that ozone levels typically are not elevated when associated with air trajectories from the west or west-northwest even with other favorable meteorology for ozone formation.

Figure 40

Top 10 Highest Temperature with Mostly Sunny Conditions at Chicopee - 2016

HYSPLIT 36-Hour Back Trajectories – July 6, 2016

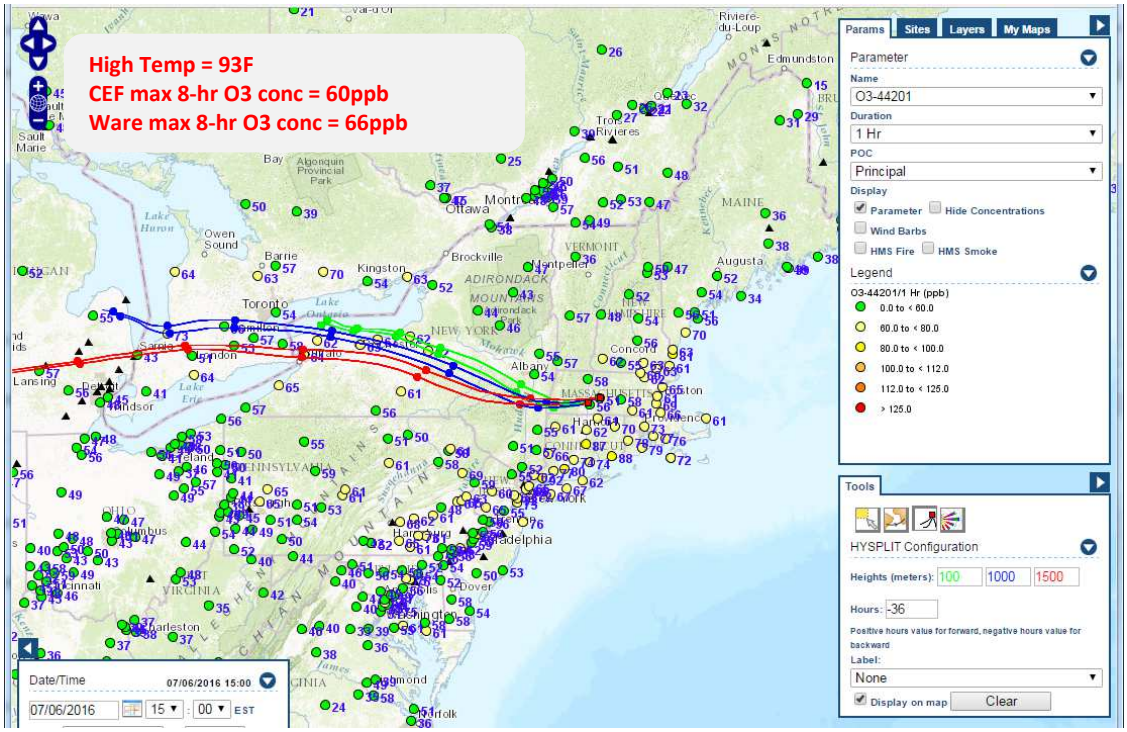


Figure showing late afternoon ozone levels in the northeast US on July 6, 2016. 36-hour back trajectories calculated with HYSPLIT model also overlaid on map showing air transport generally from the west to the Chicopee and Ware monitoring locations. Display generated via AirNow-Tech (http://www.airnowtech.org/)

Figure 41

Top 10 Highest Temperature with Mostly Sunny Conditions at Chicopee - 2016

HYSPLIT 36-Hour Back Trajectories – July 22, 2016

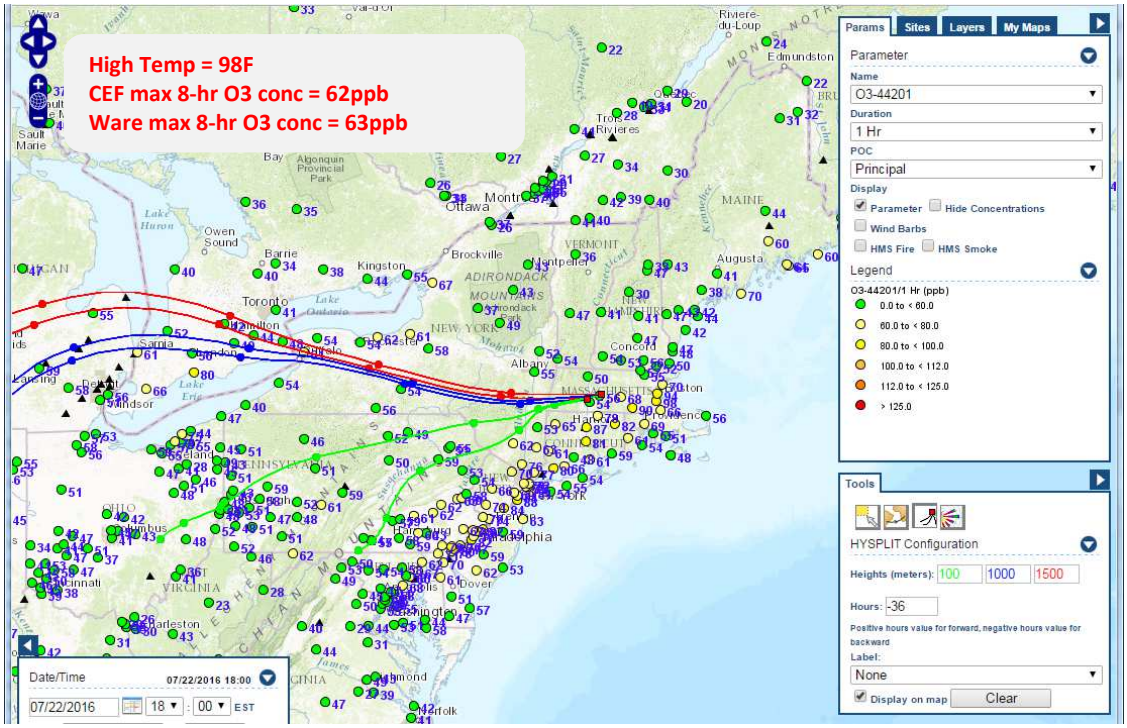


Figure showing late afternoon ozone levels in the northeast US on July 22, 2016. 36-hour back trajectories calculated with HYSPLIT model also overlaid on map showing air transport generally from the west to the Chicopee and Ware monitoring locations. Display generated via AirNow-Tech (http://www.airnowtech.org/)

Figure 42

Top 10 Highest Temperature with Mostly Sunny Conditions at Chicopee - 2016

HYSPLIT 36-Hour Back Trajectories – July 28, 2016

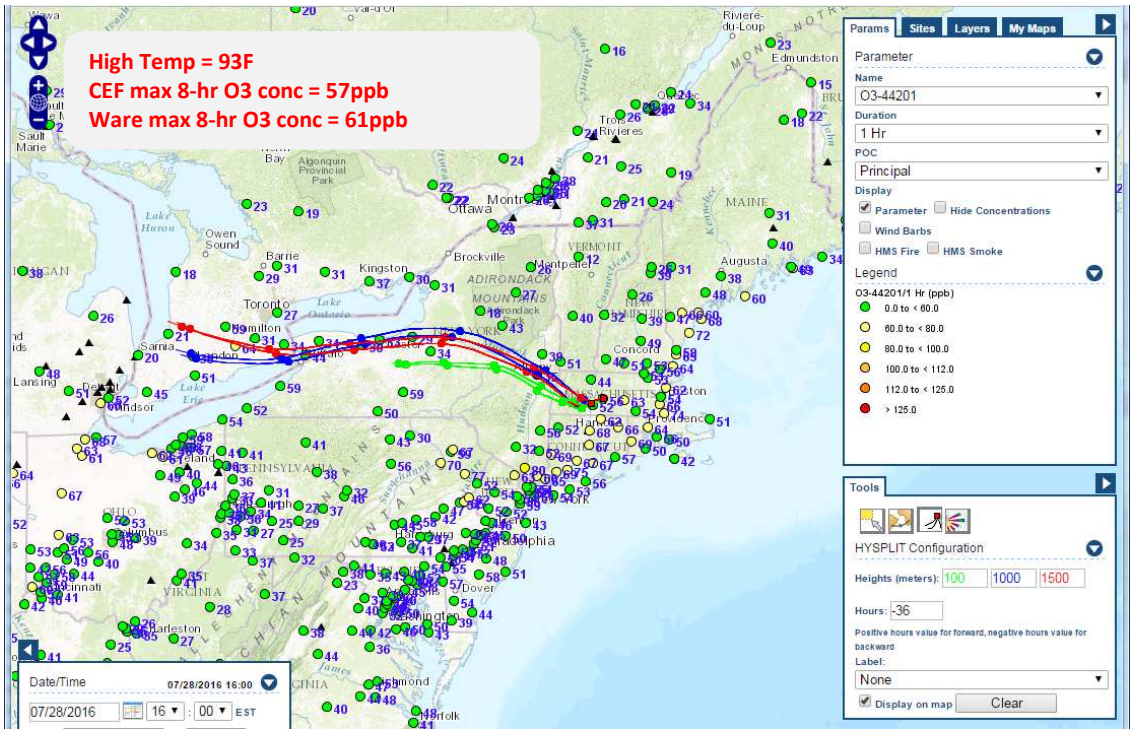


Figure showing late afternoon ozone levels in the northeast US on July 28, 2016. 36-hour back trajectories calculated with HYSPLIT model also overlaid on map showing air transport from the west-northwest to the Chicopee and Ware monitoring locations. Display generated via AirNow-Tech (http://www.airnowtech.org/)

Figure 43

Top 10 Highest Temperature with Mostly Sunny Conditions at Chicopee - 2016

HYSPLIT 36-Hour Back Trajectories – September 9, 2016

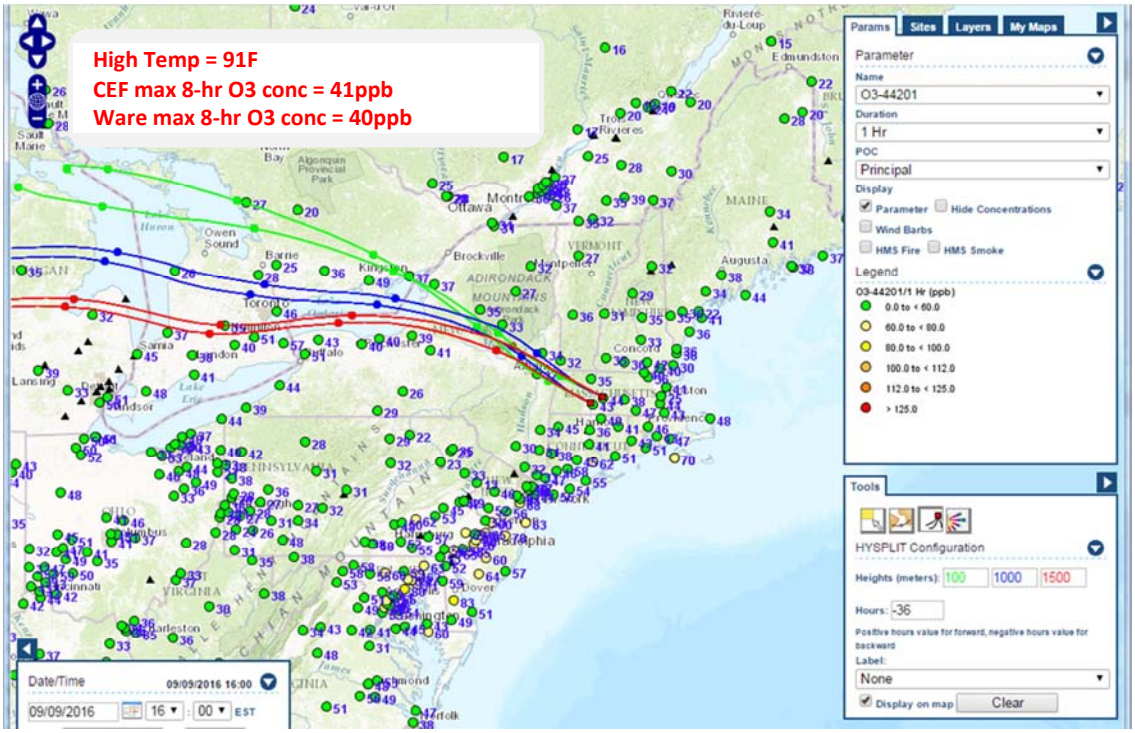


Figure showing late afternoon ozone levels in the northeast US on July 6, 2016. 36-hour back trajectories calculated with HYSPLIT model also overlaid on map showing air transport from the west-northwest to the Chicopee and Ware monitoring locations. Display generated via AirNow-Tech (http://www.airnowtech.org/)

12. Event Caused by Human Activity that is Unlikely to Recur at the Particular Location

At the time of this demonstration no official cause of the Fort McMurray wildfire had been determined. However, investigations to date and analysis of the fire have strongly suggested that human activity was the likely cause. The on-going investigations point to an origin approximately 10 miles to the southwest of the City of Fort McMurray. This location is in a remote densely forested area. Weather conditions at the time have led investigators to discount lightning as a probable cause since there were no storms in the area. Below are excerpts from news articles in the Canadian Press describing the wildfire.

From Canadian Press January 17, 2017

> *The fire began in a remote forested area southwest of the city on May 1 during a spell of unusually hot and dry spring weather. By suppertime on May 3, the flames were inside the city and all of Fort McMurray was under a mandatory evacuation order.*

From Canadian Press May 6, 2016

> *Mike Flannigan, a professor of wildland fires at the University of Alberta, says the fire's proximity to the city, as well as data that shows there were no lightning strikes in the area, lead him to believe the cause of the fire was likely human.*
>
> *Officials were still investigating the cause of the latest fire, which remained out of control on Wednesday as it raged around Fort McMurray, a city of about 80,000 people located 435 kilometres northeast of Edmonton.*
>
> *However, Flannigan said weather conditions in Western Canada have been perfect for wildfires as the warm, dry winter has led to an abundance of dead, dry leaves and wood ready to light up.*
>
> *"It's really extreme conditions," he said, adding that the low humidity and lack of green vegetation combined with windy conditions contributed to the incredibly intense fire in the northern Alberta city.*

From CTV News (http://www.ctvnews.ca/canada/fort-mcmurray-wildfire-likely-result-of-human-activity-rcmp-1.2946737) and Royal Canadian Mounted Police (http://www.rcmp-grc.gc.ca/ab/news-nouvelles/2016/06/160614-fort-mcmurray-investigation-enquete-eng.htm)

> Fire investigators in Alberta have determined a wildfire that devastated parts of Fort McMurray last month was "most likely" the result of human activity.
>
> In a news release, the RCMP said that investigators ruled out lightning as the "probable cause" of the wildfire, which began in early May and prompted a massive evacuation in several Fort McMurray communities. Officials have dubbed the wildfire MWF-009.

> As a result, the RCMP is asking for the public's help in the investigation into the cause of the wildfire, which an airborne forestry crew first spotted 15 kilometres southwest of Fort McMurray on May 1.
>
> "The role of the RCMP is to determine whether a criminal offence was involved in the ignition of the fire MWF-009," the statement read. "To date, police have not made a determination on how the fire was started, but would like to speak with anyone who was in the popular wilderness area known as the Horse River Trail System between April 29-May 5."

EPA's Exceptional Events Rule (40 CFR 50.1(n)) defines a wildfire as "…any fire started by an unplanned ignition caused by lightning; volcanoes; other acts of nature; unauthorized activity; or accidental, human-caused actions, or a prescribed fire that has developed into a wildfire. A wildfire that predominantly occurs on wildland is a natural event." The Rule defines "wildland" as "Wildland means an area in which human activity and development are essentially non-existent, except for roads, railroads, power lines, and similar transportation facilities. Structures, if any, are widely scattered" (40 CFR 50.1(o)).

Based the evidence, the Fort McMurray wildfire qualifies as a wildfire as defined in 40 CFR 50.1(n) because unplanned human activity or arson caused the unplanned wildfire event. EPA generally considers the emissions of ozone precursors from wildfires on wildland to meet the regulatory definition of a natural event at 40 CFR 50.1(k). This wildfire event occurred predominantly on wildland as documented above; therefore, the Fort McMurray wildfire may be considered to be a natural event and may be treated as an exceptional event.

13. Event Not Reasonably Controllable or Preventable

The Fort McMurray wildfire spread rapidly from its initial origin due to very dry conditions in the area along with warm weather and high winds. The level of severity and increased size that the fire attained in a very short period of time prevented response personnel from controlling the fire. The following news article describes the early stages of the fire.

From CNN May 4, 2016

> *The sky in northern Alberta's Fort McMurray resembled a wall of fire and smoke Wednesday as a mammoth inferno swallowed parts of the Canadian city.*
>
> *Authorities ordered the evacuation of about 88,000 people, including the entire city of Fort McMurray, the Regional Municipality of Wood Buffalo said. Reception centers for evacuees were being set up in Edmonton.*
>
> *A state of emergency across the province was declared later in the day.*
>
> *The blaze has already destroyed 80% of Fort McMurray's Beacon Hill community, RM Wood Buffalo said.*
>
> *The wildfire began Sunday and had torched 24,710 acres by Wednesday, CNN partner CBC News said. The cause of the blaze remains unclear.*
>
> *In all, some 1,600 structures have been destroyed by the fire, Alberta Premier Rachel Notley said. However, there have been no reports of deaths or injuries, officials said.*
>
> *High winds, warm weather and dry conditions were expected to create "explosive conditions" for fire growth and make it difficult for firefighters to keep up, Alberta forestry manager Bernie Schmitte said.*
>
> *The fire is "challenging all of us," he said.*
>
> *About 250 firefighters were on the ground, while the skies are saturated with anti-fire aircraft.*
>
> *"All our efforts to control and contain the fire were challenged by this extreme fire behavior," Schmitte said. "Efforts were also hampered by smoke conditions. Basically fire behavior was beyond all control efforts."*
>
> *The main challenge ahead: fierce winds gusting in different directions.*
>
> *"If it's constantly changing direction in different ways, it's hard to control a fire," Jones said.*

Based on this article and others in this submittal, the Fort McMurray fire started in a wildland ("wilderness area known as the Horse River Trail System") due likely to human activities that

authorities are not aware of.[14] MassDEP is not aware of any evidence clearly demonstrating that prevention or control efforts beyond those actually made would have been reasonable. Therefore, emissions from this wildfire were not reasonably controllable or preventable.

14. Conclusion

The Fort McMurray wildfire that began on May 1, 2016 and continued through July 5, 2016, generated high levels of ozone precursors that resulted in elevated ozone concentrations at the Chicopee and Ware monitors. The maximum 8-hour average concentrations recorded on May 25 and 26 exceeded the 99th percentile for 2016 at each monitor. In addition, maximum 8-hour average ozone concentrations recorded on these two days exceeded the 99th percentile for the entire April-September ozone seasons for the most recent six-year period (2011-2016). Meteorological conditions were not consistent with the historically high levels of ozone observed on these days. The comparisons and analyses in this section support MassDEP's conclusion that the wildfire event affected air quality in such a way that there exists a clear causal relationship between the Fort McMurray wildfire and the monitored exceedances on May 25-26, 2016, and thus satisfies the clear causal relationship criterion in EPA's Exceptional Events rule.

[14] Royal Canadian Mounted Police Press release: RCMP Seek Public's Assistance in Fort McMurray Wildfire Investigation. Fort McMurray, Alta. (June 14, 2016) http://www.rcmp-grc.gc.ca/ab/news-nouvelles/2016/06/160614-fort-mcmurray-investigation-enquete-eng.htm

15. Public Comment

According to the provisions in the Exceptional Events Rule (40 CFR 50.14(c)(1)(i)), air agencies must "notify the public promptly whenever an event occurs or is reasonably anticipated to occur which may result in the exceedance of an applicable air quality standard." In addition, according to 40 CFR 50.14(c)(3)(v), air agencies must "document [in their exceptional events demonstration] that the [air agency] followed the public comment process and that the comment period was open for a minimum of 30 days…." Further, air agencies must submit any public comments received to EPA and address in their submission those comments disputing or contradicting the factual evidence in the demonstration.

MassDEP routinely posts forecasts of ozone levels on its MassAir website (http://public.dep.state.ma.us/MassAir/Pages/MapForecast.aspx?&ht=1&hi=108). MassDEP posted forecasts for the elevated ozone levels caused by the Fort McMurray fire event.

MassDEP is holding a 30-day public comment period on this Draft Exceptional Events Demonstration, which is posted on MassDEP's website at: http://www.mass.gov/eea/agencies/massdep/news/comment/#ReportsPlansData2 MassDEP will accept written comments on the draft Exceptional Events Demonstration until 5:00 p.m. on May 19, 2017. Written comments may be submitted by email (preferred) or mail to:

Steve Coughlin (Steven.Coughlin@state.ma.us)
Massachusetts Department of Environmental Protection
One Winter Street, 7th Floor
Boston, MA 02108

Attachment 1

Q/d Analysis from Connecticut Department of Energy and Environmental Protection (CTDEEP)

Q/d Analysis

EPA guidance [Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations, Final, EPA, September 2016] recommends conducting a Q/d analysis as a rough assessment of the ability of a wildfire to cause increased ozone concentrations. The Q/d analysis is simply a comparison of the ration of Q, the daily tons of VOC and NOx emitted from the fire, to d, the distance in kilometers from the fire to the point of concern. If the Q/d value compares favorably to analytical data from other fires, then the fire can be presumed to have had a causal effect on ozone concentrations at the point of concern.

EPA guidance indicates that a fire should have a Q/d in excess of 100 tons per day per kilometer (tpd/km) in order to be considered to have a clear causal impact on ozone. EPA developed this value based on analyses of four fires which occurred in 2011.

Estimate of Q

The emissions from the fire can be estimated using information from EPA's AP-42 Compilation of Air Emission Factors Section 13.1 Wildfires and Prescribed Burning. The equations given are as follows:

Fi = Pi * L (Equation 1)
Ei = Fi * A (Equation 2)

Fi = emission factor (mass of pollutant/unit area of forest consumed)
Pi = yield for pollutant "i" (mass of pollutant/unit mass of forest fuel consumed)
= 12 kg/Mg (24 lb/ton) for total hydrocarbon (as CH4)
= 2 kg/Mg (4 lb/ton) for nitrogen oxides (NOx)
L = fuel loading consumed (mass of forest fuel/unit land area burned)
A = land area burned
Ei = total emissions of pollutant "i" (mass pollutant)

Combining equations 1 and 2, we have:

Ei = Pi * L * A

Pi is given above for total hydrocarbons and for nitrogen oxides. The fuel loading is given in AP-42 for different regions of the United States and ranges from 9 to 60 tons per acre. Conservatively, we will estimate a low end emission rate using 10 tons per acre which is associated with North Central US conifer forests. Note that our results could increase by a factor of 6 were we to expect the high end of emissions.

The Alberta government reported that by June 10, 2016 the fire ultimately covered 589,995 hectares (1,457,909 acres) with a perimeter of 996 kilometers (618 miles). For reference, the total land area of Rhode Island is approximately 270,000 hectares.[15] The chart below indicates the total area covered by the fire as reported by the Alberta government[16]. During the week prior to the exceptional event in Connecticut the fire grew by approximately 60,000 hectares (148,263 acres).

Therefore, ignoring the smoldering of approximately 500,000 hectares we estimate the total hydrocarbon emissions from the week to be:

Ehc = 24 lbs of HC / ton of forest fuel consumed * 10 tons fuel / acre * 148,263 acres

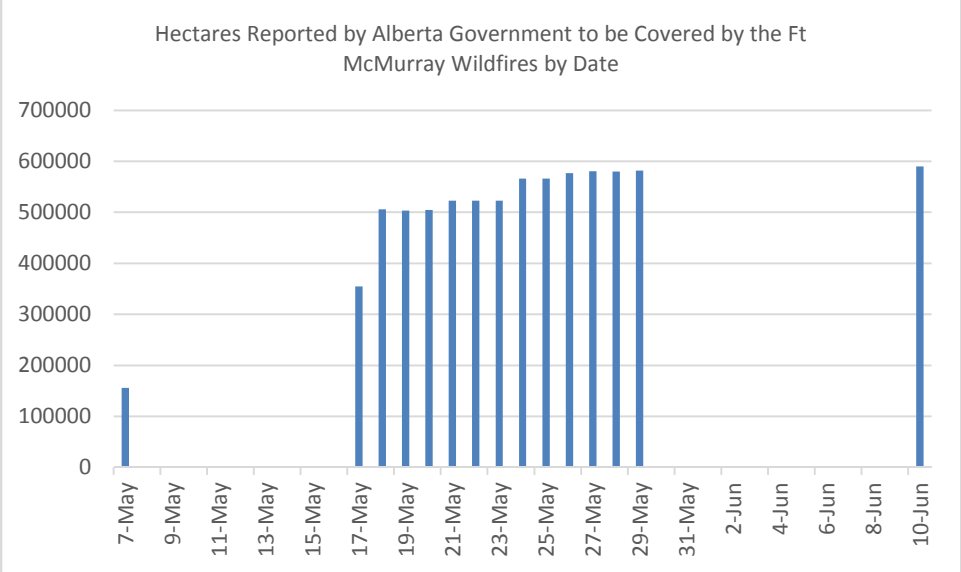
Ehc = 35,583,120 pounds of HC

Ehc = 17,791 tons of HC emitted during the period from May 19 to May 24

Similarly for NOx:
Enox = 4 lbs of NOx / ton of forest fuel consumed * 10 tons fuel / acre * 148,263 acres

Enox = 5,930,520 pounds of NOx

Enox = 2,965 tons of NOx emitted during the period from May 19 to May 24



[15] Any large area estimate can only be considered comprehensible if compared to the State of Rhode Island.
[16] https://www.alberta.ca/release.cfm?xID=41701E7ECBE35-AD48-5793-1642C499FF0DE4CF [Final Update 39: 2016 Wildfires (June 10 at 4:30 p.m.), Alberta Government]

Q is the total daily emission rate in tons per day of reactive hydrocarbons and nitrogen oxides. EPA recommends, in the exceptional events guidance, that only 60% of the hydrocarbons should be considered reactive. Therefore the reactive hydrocarbon emissions become rHC = 0.6 * Ehc or 0.6 * 17,991 = 10,794 tons of reactive HC emitted during the period of interest. No adjustments are suggested for the NOx emissions. Therefore the total rHC and NOx emissions over the period are 10794 + 2965, or 13,759 tons over the six days. On average this results in a daily emission rate, or Q, of 2293 tons per day.

Estimate of d

Based on the large distance, we will not present individual analyses for each monitor in Connecticut but estimate the distance from the Fort McMurray fire to the most distant point in Connecticut. We will therefore use a value of d of 3286 kilometers, the flight distance from Fort McMurray to Stonington, CT.

Q/d Estimate

Using the values determined above, Q/d then becomes 2293 tpd divided by 3286 km or 0.69 tpd/km. This value is well below the EPA recommended level of 100 tpd/km indicating clear causality.

Taking a less conservative approach and using the maximum extent of the burn area over the life of the fire, the result would be a Q/d of 40.8 tpd/km. Still sufficiently below the EPA recommended threshold for establishing clear causality. Recalling that a worst case fuel loading would increase our results by a factor of six, Q/d would in this case result in 240 tpd/km and would indicate clear causality. While this approach might be justified by the ongoing smoldering of the peat, the intensity of the Fort McMurray fire, variability in the burn rate and other factors, it is difficult to justify without further details that may only be obtained through estimates which introduce their own error.

Taking a slightly different approach we consider the basis for the EPA guidance and look at emissions from one of the four fires EPA relied on in developing their guidance. Appendix A2 of the EPA guidance indicates that EPA based their conclusions on 12 km grid CMAQ modeling of four 2011 multiday fires: Wallow, Waterhole, Big Hill and Flint Hills. Emissions from the fires were based on a program called SMARTFIRE. Using information available on the Wallow Fire, we approximate the emissions that might be calculated for the Fort McMurray fire.

The Wallow Fire burned in eastern Arizona and western New Mexico from May 29, 2011 through July 8, 2011 and burned 841 square miles (538,240 acres) by June 26th. The maximum daily emissions from that fire were reported as approximately 15,000 tons of rVOC and 1,000 tons of NOx. [Simulating Fire Event Impacts on Regional O3 and PM2.5 and Looking Forward Toward Evaluation, Kirk Baker, EPA October 5, 2015 and Using SOAS and related field study data for scientific and regulatory modeling, Kirk Baker, EPA, undated; both are slide presentations] If we scale this fire up by a factor of three to approximate the acreage burned in the Fort

McMurray fire, then we have daily emissions as high as 45,000 tons for rVOC and 3,000 tons for NOx. These emissions produce a Q of 48,000 tpd and Q/d becomes 14.6 – still well below EPA expectation for causality.

Noting the wide variability in emissions estimates from different approaches, and as the Q/d method does not generally satisfy the expectation of a clear causal impact, we present other evidence demonstrating that the plume from the Fort McMurray fire caused elevated ozone levels in Connecticut.